Commercial Cellular Architecture for Dismounted Battle Command

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Executive Summary

Problem Definition The Army's Soldier as a System requirement identifies capability gaps with respect to dismounted battle command and situation awareness. As compared to their mounted peers, dismounted soldiers lack effective radio communications, situation awareness displays, and request or reporting systems that integrate with other elements of the combined arms team. In particular, networked voice and data communications, a user-defined situation awareness picture, networked lethality, and mission planning and rehearsal are not available to dismounted soldiers via their organic command and control systems.

The Army's Nett Warrior system will address some of the needs for dismounted command and control. This program is slated to reach initial operating capabilities in 2012 with improvements and full operating capabilities in 2016. Even after successful development and fielding of the Nett Warrior system, complemented by the SINCGARS (ASIP) radio, there will still be some challenges and capability gaps with respect to dismounted command and control. First, these systems are scheduled to be fielded to infantry units. However, many other units perform dismounted operations. In addition, concerns about overall system weight and cost remain. Finally, the challenge of integrating allied and host nation forces will be difficult with these systems.

Technical Approach This project looks to emerging commercial technologies for mobile cellular networks as a cost effective means to fill these gaps. These technologies are in wide use across the international commercial sector and allow robust and high bandwidth communications in a very small package. They are employed in all types of terrain, and international standards have emerged that allow communications between disparate systems.

This project performed stakeholder analysis across the dismounted community to better define the overall value this system brings to the battlefield. Based on this analysis, we developed an overarching value model to support value focused design of alternatives. These alternatives were evaluated in a modeling and simulation environment that assessed communications effects and tactical effects on the battlefield. A significant portion of the effort for this project was the development of these modeling and simulation capabilities. In addition, network and device security concerns were integrated into the analysis.

A parallel effort leveraged an international command and control standard, the Coalition Battle Management Language (CBML) to develop interoperability protocols, orders passing, and message passing via mobile devices between coalition partners.

Results With respect to analysis results, the study team concluded that a brigade/battalion owned CDMA network delivered the most value at the lowest cost as compared to Nett Warrior systems. This is a standalone unclassified network owned by the brigade. The brigade decides who to allow to enter the network and what information to provide on that network. The network consists of static cell towers on bases, mobile cell towers in vehicles, and, if necessary, dismounted cell towers covering small patrols. Cell to cell communications are handled by a portable high bandwidth device such as the L3 Communications Rover 5. This system also allows the integration of UAV video into the network. Individual soldiers or vehicle commander carry commercially available handheld phones - optionally with external amplifiers and antennas to support longer ranges.

Security is a significant concern for mobile commercial technologies. However, after a visit with the National Security Agency's secure wireless division, we found that a combination of commercially available encryption technologies would be adequate for a disconnected brigade level network. For transmission, these technologies included a secure VPN coupled with an additional layer of data encryption to pass both voice and data along

the data channel. The CDMA spread spectrum technology added an additional layer of inherent security and jamming resistance. Device security could be accomplished by encrypting all data stored on the device along with a combination code/token authentication system. This gives network managers an ability to almost instantly grant or deny access to users as the tactical situation dictates.

Modeling and analysis showed that, although this network had shorter radio ranges than current systems, radio relay technologies significantly improved performance to acceptable levels. Its overall lower weight, intuitive interface, and expanded features delivered significantly higher value. In addition, the availability of commercial technologies drives the cost of this system well below the Nett Warrior system, and it allows more users on the network because of the low relative cost of individual devices.

In addition to these analysis results, the study team worked with simulation and communications experts to develop a robust communications analysis suite that enables both stand-alone communications analysis and communications effects integrated with combat simulation. The core of this infrastructure is the COMPOSER (The Communications Planner for Operational Effects with Realism) model developed by US Army Communications Electronics Research Development and Engineering Center. In stand-alone mode, it quickly models complex communications architectures at the unit level. When integrated with the Army's Modeling Architecture for Technology, Research, and Experimentation, it allows simulation players to see situation awareness pictures as affected by communications propagation and interference.

When the CBML message passing capability was integrated with this architecture, the project yielded a prototype mobile phone system that could exchange orders, messages, and situation awareness with the Army's One Semi-Automated Forces (OneSAF) simulation system.

Contents

1 Background

Shoot, move, communicate. These are the critical actions a dismounted combat unit must be able to perform in order to be effective on the battlefield. Of these three actions, communication is the most important because it precedes and directs how a dismounted unit shoots and moves. Communication is also key in coordinating combat and logistics support. Unfortunately, the current communications systems in use are much more effective for mounted units than dismounted units. Our mission is to provide analysis that will inform and direct the decisions of Army leadership as it provides new communication systems to all dismounted units which modernize and improve military communications. Some ideas that are being considered include tablet PC or smart phones. Some issues with these commercial devices are that the army would have to coordinate with the companies themselves and secure the devices.

Currently in theater they use a SINCGARS (ASIP) radio. It has the ability to talk over different radio nets, but it is limited to voice. The stakeholders we talked to seemed to be content with the way the system worked and said that in a firefight they would "forget about the fancy technology and resort to the way they had always done things". The way they had always done things would refer to using a radio to communicate and carry out the mission. The SINCGARS radio is effective, but the question is, "How much more effective an alternative system would be in comparison to what is currently being used in theater?"

2 Stakeholder Analysis

Prior to developing a value model and considering alternatives, the design team interviewed a series of experienced stakeholders from the West Point community to try to understand their needs with respect to dismounted command and control.

Army SFC: He has spent over 15 years enlisted in the infantry. He was adamant about the army in general not knowing how to use the technology they already had and how adding new technology would not be helpful. He said that only the platoon sergeant/platoon leader and up would need the new technology we are recommending. Anything below this would take far too long to train, and it would not be helpful in any manner. He liked all of the operational activities that we have and would be interested to see a piece of technology that could use them relatively easily. In addition, he was doubtful on the idea of us translating between languages with our technology, particularly when working with the Afghanistan Police.

Army Captain- deployed to Iraq 2006-2007 with the 101st Airborne Division (Air Assault). He picked up a platoon mid tour and was immediately thrown into action. He was only deployed for five months, but was wounded three times. These consisted of two IEDs and one ambush. He wished he had some sort of technology that tracked his unit's actions and enemy actions in the area because he believed the enemy had operated in the area previously.

Army 1LT: We asked him if he or any of his Soldiers had used the Nett Warrior system before. He had not personally used Nett Warrior, but his platoon sergeant had in 2008 at Ft. Benning during a training exercise. The feedback he gave was that it was too heavy for the benefits it gave his unit. He continued saying that he would not bring it outside the wire with him.

Army SFC: He has served in the Ranger Regiment and participated in several deployments. His main focus was ensuring that whatever technology was being considered as a candidate solution should be easy to train soldiers to use. He said one of the largest issues he had noticed is that soldiers often do not know how to properly operate the communications equipment they currently have. If soldiers do not know how to properly use the technology, it is essentially useless. He used communications technology in the Ranger Regiment similar to some of the systems being examined by our capstone group. This equipment provided video feed, GPS, and text capabilities. He warned that these systems are often very expensive, and may not always provide enough value for that cost. During operations, he said most of the rangers equipped with these devices did not use them. He advised that we find something durable, that is easy to use/train to use, and provides an array of capabilities such as GPS and text communications that would benefit a soldier only at times when not engaged with the enemy. He also advised that no one below the level of squad leader should receive a system.

Army SFC: He has served 12 years in the Army through multiple deployments. He said the systems would be useful in dismounted command and control, but in order for our system to be useful to the soldier it would need to be durable. He commented that if it broke every time a soldier dropped it, the soldier would not carry it. He also noted that the batteries used in this system would need to last at least 12 hours. The batteries would need to be small and light in order to lessen the amount of weight carried by a soldier on a mission. Furthermore, this system would need to have various layers of security to protect the information on it if it were lost or stolen. Otherwise, this system would be too much of a security risk to take on missions. He stated that this system should be able to support voice and text communications, it should be light, using it should be easy, and it should facilitate the request and coordination of combat support assets.

3 Operational Architecture

The capabilities, operational activities, values, and metrics of assessment for the proposed system were organized into a systems architecture for dismounted command and control.

3.1 Capabilities Viewpoint

The Capability View 1 (CV-1) is part of defining the capabilities we want for our system. This view is the highest level view and shows the overall vision of the system. Our vision for this system is to provide dismounted command/control to different unit types. In this view we display the desired effects or the organizational objectives. The desired effects are more specific than the vision; however they feed into the vision of the overall system. After talking to stakeholders, we found that we have four capabilities that define our system. The entire CV-1 can be seen in Figure 1.

The Capability View 2 (CV-2) is part of the system architecture that defines each capability. The capabilities of this system are communicate with higher and adjacent units, understand friendly situation, understand enemy situation, and simplify and expedite reporting/requests. In Figure 2 you can find the descriptions of each of these capabilities. The most important fact about each of these capabilities is that they are all looked at the platoon level.

3.2 Operational Viewpoint

The OV-1 is a visual representation of the capabilities we have found to be essential through stakeholder analysis. Not all capabilities or mission threads are shown in the OV-1, however, the concept of the capabilities are captured. The benefit of the OV-1 is that it shows not only what capabilities a candidate solution technology may possess but also shows the capabilities necessary to a dismounted Army mission. A prominent takeaway from the OV-1, shown in Figure 3, is the level of connectivity that the dismounted platoon or soldier will experience when using the candidate solution technology. They will be connected to UAV, aircraft, other dismounted soldiers, vehicles, mortars/artillery, GPS, and higher headquarters.

The OV-5a as shown in Figure 4, covers our system capabilities, operational activities, and system functions. It is using the same system capabilities as shown in the CV-2. The important elements of the OV-5a are the Operational Activities: Communicate with Allied Forces, Acquire Video Feed, Send SITREP, Request MEDEVAC, Request EOD, Track Enemy Forces, Track Allied Forces, Request Fires, Conduct Movement during the Mission, and Prepare for Mission. From these activities we decided on functions we would want our system to perform, and these will further be broken down in our Value Hierarchy.

We created a mission thread for each of our Operational Activities mentioned in Architecture OV-5a. These mission threads are shown in Annex A, depicted as a series of OV-5b - Operational Activity Models. These Mission

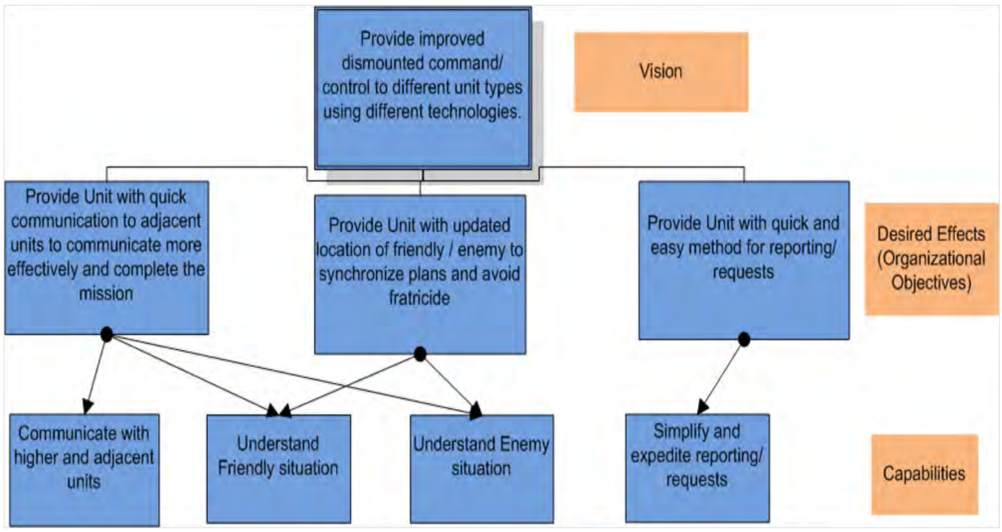

Figure 1: CV-1 Capabilities View 1 - Vision.

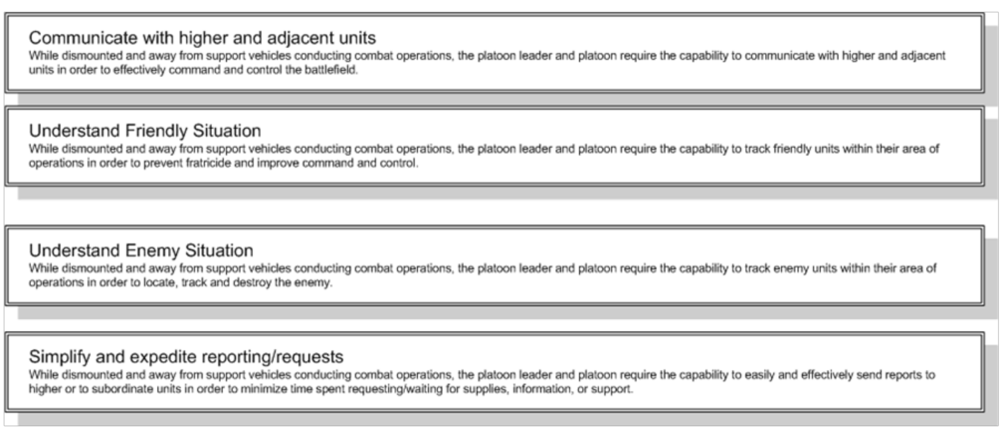

Figure 2: CV-2 Capabilities View 2 - Capability Taxonomy.

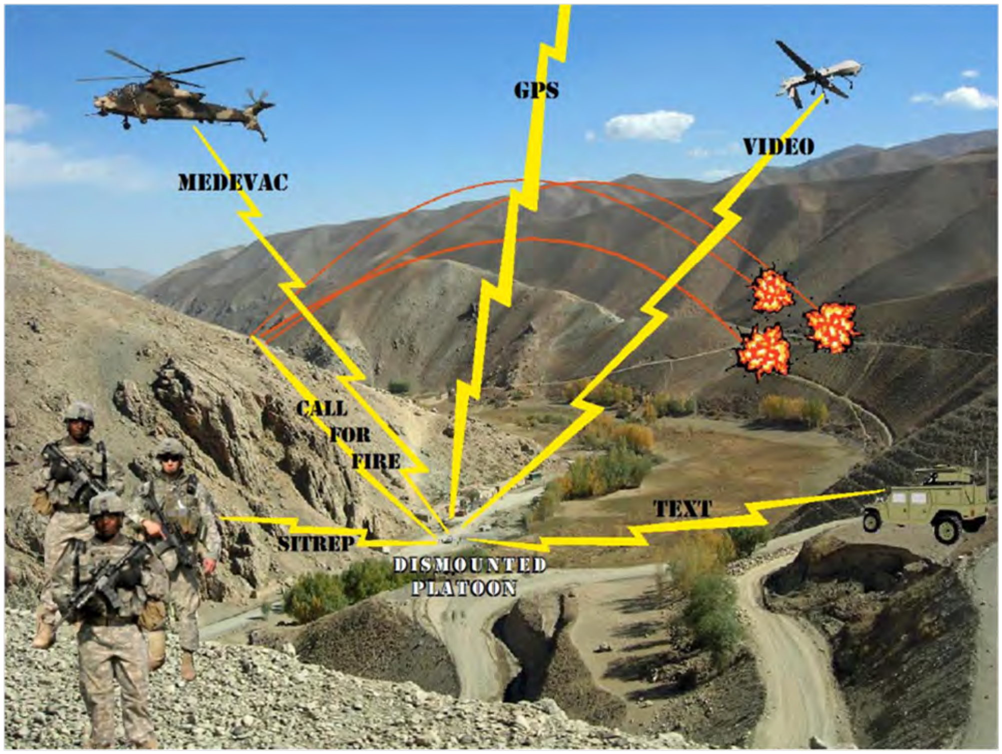

Figure 3: OV-1 - High Level Operational Concept Graphic.

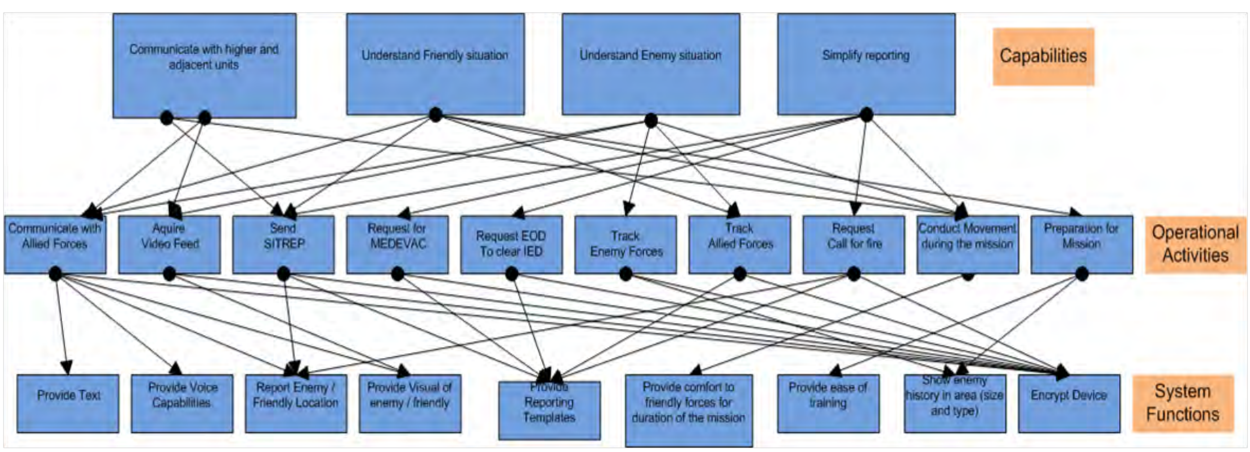

Figure 4: OV-5A - Operational Activity Decomposition Tree

Threads go through each of our operational activities step by step to show the different steps that our system is going to be needed for. We need to make sure that the software has the capability to perform all of our desired effects. Most of the threads make use of an radiotelephone operator (RTO), which is currently how reports are done on the SINCGARS radio. If the system we choose at the end of this project is simple and quick enough, the platoon leader or platoon sergeant may be able to perform the role of the RTO and save time instead of translating to the RTO to send messages. Another point of the mission threads is to show things that you could not do with the current system, such as requesting a video feed from a UAV. With these mission threads we can show what our system is going to need to do. They give us a framework for where to go with our software and hardware requirements.

4 Value Modeling

The Value Hierarchy is a model that gives us insight to the operational activities, system functions, and system objectives. From our stakeholder analysis we learned that users would like the system to perform the following activities: communication with allied forces, acquire video feed, send SITREP, request MEDEVAC, request EOD to clear IED, track allied forces, request call for fire, conduct movement during the mission, track enemy forces, and prepare for mission. These operational activities feed into our nine system functions. System functions are the functions that the dismounted command and control system performs during the dismounted squad's operational activities. The nine system functions are: provide text, provide voice capabilities, report enemy/friendly location, provide visual of enemy/friendly, deliver report templates to desired unit (EOD, SITREP, call for fire, MEDEVAC), provide comfort to friendly forces for duration of the mission, provide ease of training, show enemy history in the area, and encrypt the device. Each of our system functions has 2-3 objectives. The entire value hierarchy is shown in Figure 5.

Our system functions fall into the bottom of our value hierarchy. Each system function has at least one value measure attached to it. The value measures are the criteria for how we are going to score our alternatives. Most of our value measures have an objective measure to them. For example screen resolution has a value measure of mega-pixels. When looking at alternatives we will research how many mega-pixels it is and score it according to our value model. However, some of our value measures are subjective because they have star ratings. By "star ranking," we refer to a constructed scale where a user will pick up our device and rate it from 1-5 stars based on how that individual feels the system should be scored. Our system objectives and value measures can be found in ANNEX B.

After talking to stakeholders, we gathered that they have many important value measures. However, we learned that not all the value measures are as important to them. For example, the number one value that stakeholders said is that if it is too heavy they will not use it at all. One of the value measures is precision of location for squad size element. This value measure means how accurate the device will report a friendly/enemy unit. Stakeholders stated that this would not be as important as weight, battery life, or simplicity. The value measures that stakeholders said are most important are in the upper left corner of the matrix and the least important are the value measures in the bottom right corner of the matrix. The entire matrix that lists all of our value measures can be seen in Figure 6.

Value models give a numeric value score to a specification of the system. With these we can compare the value of our base case to the value of the different options we are weighing against each other. This will allow us to get a total number that we will be able to translate into a score of 1 to 100 which will be talked about in the Swing Weight Matrix portion of this report. We currently have 17 value models for our 17 System Objectives, each with a shape depending on the value associated at different levels. We determined the shapes of the value models after talking with our stakeholders about what they thought was important to take this piece of equipment on dismounted missions. For example, weight is an extremely important consideration to the war fighter. The war fighter will already be carrying 50-70+ pounds at temperatures up to 120° F. After realizing how important weight would be, we went back to the war fighter

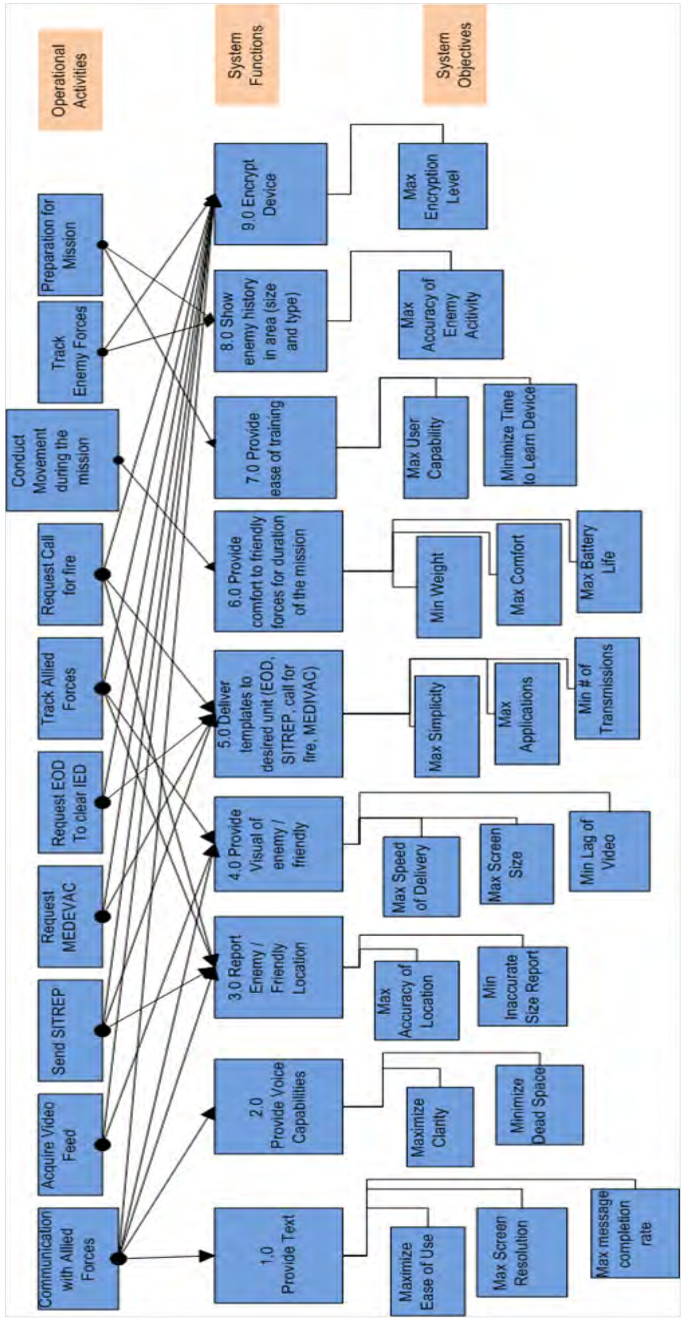

Figure 5: Value Hierarchy

		Level of Importance of the Value Measure					
		High		Medium		Low	
variation	High	Weight	100	Fragmented Video	90	Applications	20
		Battery Life	100	Frame Rate	80		
		Classification	100	Accuracy	80		
		Training Difficulty	100				
	Medium	Simplicity	90	Send/Receive Time	80		
		Screen Clarity	85	Voice Clarity	70		
		Completion %	85	Transmissions	60		
		Propagation	85	Storage Space	55		
	Low	Comfort	70	Time to Learn	50	Precision of Location	15
						Precision of Size of Unit	15

Figure 6: Swing weight matrix. This matrix gives a weight to each value measure based on both the importance and variability of that measure with respect to the range of feasible alternatives.

and asked how much additional weight they would be willing to carry to make this command and control unit desirable. We set our ranges of 0 lbs as ideal and 10 lbs as so heavy that they would not take it on the mission. All of our value models are shown in ANNEX C.

5 Alternatives

The alternatives analyzed in this project are Nett Warrior, tablet PCs, and Smartphones. Our current baseline and what is being used across the Army, the SINCGARS (ASIP) radio. The Nett Warrior is a device worn by the war fighter and gives the user more capabilities than the ASIP radio. In addition to voice, it provides video, tracking of friendly and enemy forces, and can show the unit's location to higher. It is relatively heavy in comparison to a tablet PC or smart phone. A tablet PC or Smartphone are also much less expensive and therefore can be more easily replaced. One problem with the tablet PC and Smartphone is that they are unsecure, while Nett Warrior and the ASIP radio have been cleared to operate on SECRET networks by the National Security Agency (NSA). A tablet PC and Smartphone are extremely similar. The tablet has a larger screen than the Smartphone, but does not have voice capability. One big disadvantage of these two options is that they are less durable than the Nett Warrior or the ASIP radio.

The tablet and Smartphone alternatives each include an unclassified secure mobile cell network at the brigade and battalion level that would enable their use in an austere environment. The Army's Connecting Soldiers to Digital Apps (CSDA) program is testing the feasibility of these networks. In fact, the rapid evolution of mobile communications in the commercial sector is providing opportunities to adapt commercial technologies for military use. While the focus of this project was not to design a mobile network for military usage, the project team was able to propose a simple architecture and a set of broad system capabilities as illustrated in Figure 7. This architecture is feasible based on discussions with commercial vendors, CSDA program managers, and the results of communications modeling.

The architecture envisions a brigade or battalion level secure unclassified cellular command and control network for combined operations with coalition partners and, as determined by the brigade or battalion commander. While primary intelligence and planning will be conducted on the SECRET network, the commander will allow certain elements of operational and intelligence data to be released on the unclassified network to support current operations and command and control. The timing and scope of release will be determined by the operational situation and associated risk of compromise.

The release of data will take place via a security and

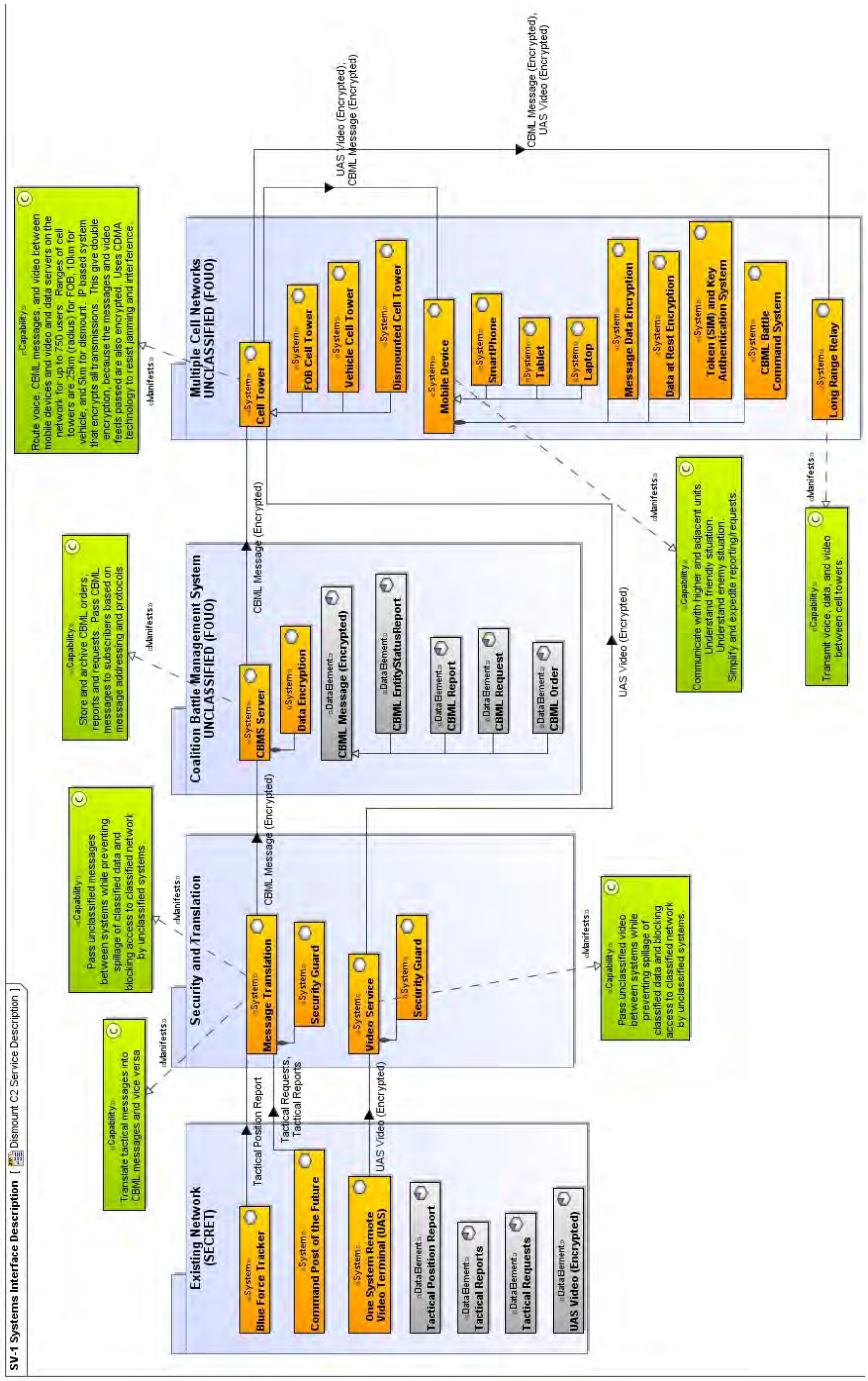

Figure 7: Systems View-1 Resource Interaction Specification for dismounted command and control alternative using tablets or Smartphones.

translation system that ensures only authorized information is released in the form of structured messages or video feeds. In addition, these guards will ensure that unclassified systems are able to pass structured data or video feeds to the higher network while protecting the higher network from unauthorized access.

In order to better support coalition operations, the network's operational data system will use Coalition Battle Management Services (CBMS). Section 7 discusses this further. Tactical messages will be routed to the server where they can be archived and compiled for subsequent publication to subscribed mobile devices. The brigade or battalion will manage message distribution across the network.

The backbone of the system is the cellular network. Several subsystems compose this network. The first of these is an array of cell towers. At brigade and battalion level, units will own a combination of Forward Operating Base (FOB) towers (brigade and battalion level), vehicle towers (company level), and dismount towers (platoon level). These towers will allow the establishment of cell networks with 25km, 10km, and 5km ranges respectively. The towers will run an IP based voice and digital network using code division multiple access (CDMA) access methods to enhance security and jamming resistance. The second element of the cell network is a collections of commercial Smartphones, tablets, and personal computers. Any of these devices will be able to access the cell network to perform command and control tasks, given they have the appropriate token and key for authentication.

If the unit needs to push out a longer range operation, the vehicle mounted or dismounted cell tower may be deployed well away from the FOB. In this case, a long-range high bandwidth communication system will link the forward deployed cell network to the main network. In order to reduce necessary bandwidth on the long range link, the unit can forward deploy a CBMS server and video server so that these media can be transmitted over the forward deployed cell network. Point to point communications will be carried over this network as well. This will limit the amount of video and data that must be passed over long range communications to the main network at the FOB.

The design team met with the National Security Agency's (NSA) Secure Wired/Wireless Division in order to understand basic security requirements for a disconnected cell network. The security system would require a token and password authentication system for access. The devices entering the network would need to be able to read the token and present a password as they authenticated onto the network. A disposable token could be given to less trusted units, and this token would only be good for a certain level of access for a certain duration of the mission. A potential alternative to the token/password is biometric authentication. Data and voice transmissions would be subject to dual encryption. The wireless signal itself will be encrypted by the phone and the cell tower prior to transmission. In addition, the respective voice or digital applications would encrypt their data prior to passing it to the device for the second layer of encryption and transmission.

Additional meetings with the CSDA program affirmed the feasibility and potential value of the proposed architecture. Several vendors already have products with similar capabilities. Lockheed Martin's MONAX system was tested by the Army Evaluation Task Force in December 2010 at the platoon level with some promising results (Army Evaluation Task Force AETF, 2010)[1]. The Rover 5 System from L3 Communications provides long range high bandwidth communication that may enable relay between disconnected cell networks. Lockheed Martin's Combat Edge System seeks to achieve interoperability with current command and control capabilities. Significant work is being done across the board to develop command and control apps for Smartphones. While the proposed architecture has not confronted every challenging issue, it is a feasible start point for serious test and evaluation and future development.

[1] The listing of commercial technologies in this report is only meant to suggest the availability of these capabilities in the commercial sector. We do not endorse any one of these technologies over their competitors, and we have not conducted and tests or evaluations of their capabilities.

6 Modeling and Simulation

Three types of modeling and simulation were conducted to test the feasibility of the proposed architecture and to compare its performance to existing or proposed systems. The first type of modeling was a web-based tool for static propagation modeling. This allowed the design team to play with system parameters in the context of an actual use scenario. The second type was a dynamic communications model that allowed an entire scenario of communications to be calculated as units moved over time. The final scenario was a combat simulation with a communications model in the loop to calculate propagation. The combat simulation also included a prototype Smartphone loaded with C2 software that interfaced with the simulation environment.

Figure 8: Modeling Scenario.

6.1 Scenario

A dismounted engineer platoon is conducting civil affairs operations in Khowst Afghanistan, shown in Figure 8. They are going to a village meeting with the elders in vicinity of Objective Raven. They will travel to this location via Route Thunder, Route Lightning, and Route Flash. They proceed down Route Thunder and dismount when they arrive at Route Lightning. While on patrol on Route Lightning they receive small arms fire. They call back to the MRAP which is at the intersection of Thunder and Lightning. The soldiers at the MRAP send a raven (a company size UAV asset). With the UAV they see the enemy size and location. They then call up an Apache who is working in their section. They quickly tell the Apache size and location of enemy. The Apache makes its run and destroys the enemy. With visual from the Raven the platoon can see that the enemy has been neutralized. They continue the mission and arrive in the village to meet with the elders. Following the meeting they return to their forward operating base (FOB).

6.2 Static Communications Modeling

The design team used an on line radio propagation model called CLOUDRF to get initial estimates of the ranges of the alternative systems (CLOUDRF.COM, 2011). The advantage of this model was its ease of use and intuitive interface. This allowed the team to understand the implications of frequency, antenna height, power, and terrain on radio propagation. They built a series of CLOUDRF scenarios that captured the difference between the cell system and the SINCGARS radio. Figure 9 shows the coverage that a cell tower on the base would have. While coverage in some places is out to beyond 15km, a large hill in the scenario prevents coverage of the dismounted avenue of approach. Figure 10 shows the coverage a vehicle mounted cell tower would have from the dismount point. This tower would allow communications along the entire dismounted route and relay back to the FOB. Figure 11 shows the improved coverage for a SINCGARS radio. For a SINCGARS, no relay station is necessary.

6.3 Dynamic Communications Modeling

COMPOSER is a Communications Planner for Operational and Simulation Effects with Realism. Essen-

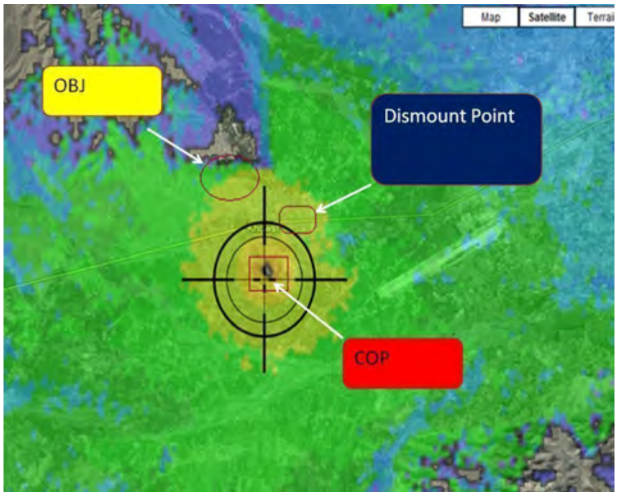

Figure 9: Coverage for cell tower on the FOB. All areas but the purple and gray areas can be covered from the base. Note the hilltop north of the base blocks the dismounted avenue of approach used for the scenario.

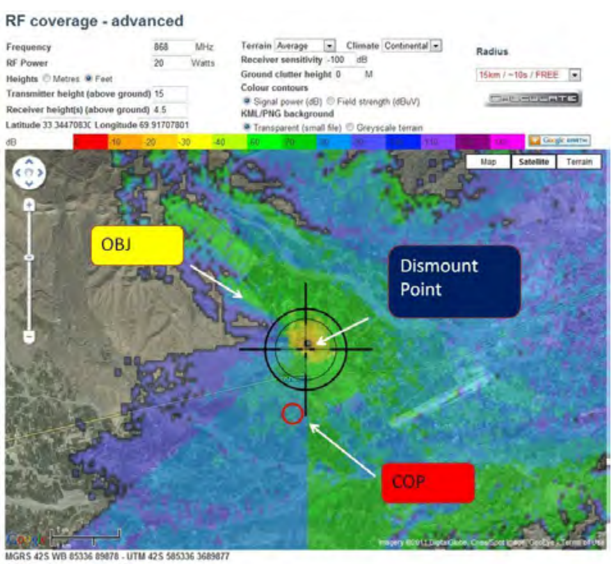

Figure 10: Coverage for the dismount point. Bringing a vehicle based cell tower to the dismount point enables coverage of the entire dismounted avenue of approach. The vehicle tower can relay traffic back to the base.

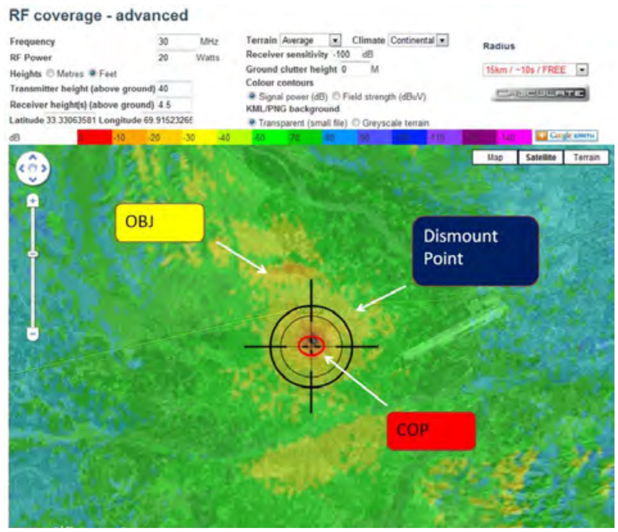

Figure 11: Coverage for a SINCGARS radio using a 40 foot antenna at the base. Because of its lower frequency and high power, the SINCGARS radio can cover the entire operation from the FOB.

tially what this means is that scenarios or troop movements can be input into COMPOSER along with terrain data from basically anywhere in the world. In addition, COMPOSER will map the connectivity of up to 2000 radio nodes in six hundred times faster than real time. All of these elements combined allow COMPOSER to model military movements on realistic terrain with the characteristics of their radios. This helps account for factors that cannot be accounted for in other simulations, such as dead space due to mountainous terrain. COMPOSER also reports over 7 types of communications traffic flows in one simulation. The benefit is that COMPOSER is capable of identifying potential network problems before they become a problem in reality. It can also help screen out candidate solution technologies before any money is invested in them.

The design team used COMPOSER to model the scenario shown in Figure 8. For that scenario, COMPOSER analyzed three different radio types: Cell phones, SINCGARS, and JTRS (Representative of Nett Warrior). Each of these radio types was simulated twice. The first simulation for each involved a base radio (tower) at COP Bear

Figure 12: Screen shot of COMPOSER 3-dimensional playback for Khowst scenario.

and one radio for the main effort that moves to Objective Raven by traveling north, around the back of the hill which Objective Raven sits upon, and up the backside of that hill to the Objective. The simulation for each radio type involved both of the aforementioned entities as well as a relay entity. This relay entity had a radio with the same parameters as the main effort radio. It travels with the main effort until reaching the east side of hill where the main effort dismounts. At that point it stops and is able to relay messages from the main effort back to the FOB. COMPOSER provided us with a large amount of data that contributed to some of our value functions. An example is the value measure "completion rate." A full list of the output provided by COMPOSER for all six simulations can be found in Figure 13. Note that the cell tower system needed a relay in order to achieve performance on par with the SINCGARS radio. The JTRS radio outperformed both systems with respect to message propagation.

6.4 Integrated Modeling Environment

The final simulation aspect of this project was to architect an integrated simulation environment that would allow military role players to exercise command and control over a combination of virtual and constructive forces in a simulated environment. This environment includes an immersive environment for role players, cell phones for role players to use in command and control and situation awareness, and constructive forces for OPFOR and for those forces not represented by role players. An important distinction between this environment and other virtual/constructive environments is the integration of a communications effects model that allows or restricts communications traffic based on the overall capabilities of the cell network, given the demand it sees. Another distinction is the capability to pass orders to constructive forces using the cell phone. The advantage of this environment is that it will allow a small unit to simulate the command and control effectiveness of different cellular architectures without having to actually build the system. This simulation architecture is shown in Figure 14. The yellow boxes represent existing systems, and the green boxes represent systems or data models that were developed or modified within this project. We will discuss each of these items further.

6.4.1 Existing Simulation Systems

The simulation capabilities developed for this project take advantage of existing Army simulation systems. The new capabilities are meant to integrate and enhance existing systems, not to compete with them or replace them. Referring to Figure 14, the MATREX federates and simulation environment are used throughout the Army's Training and Doctrine Command (TRADOC) and Research Development and Engineering Command (RDECOM) for experimentation with future capabilities (Hurt et al., 2006). Program Executive Office - Soldier, the West Point Department of Systems Engineering, and the Virginia Modeling Analysis and Simulation Center have been working over the last several years to add dismounted command and control capabilities to this federation (Kewley and Tolk, 2009). Another existing capability is the Army's Virtual Battlespace 2 (VBS2) virtual training simulation system (Program Executive Office Simulation, Training, and Instrumentation, 2011). This system allows participants to become virtual players on

	2 Cell Phone	2 Cell + Relay	2 SINCGARS	2 SINCGARS + Relay	2 JTRS	2 JTRS +Relay
Average Network Connectivity	40	61.78	44.51	66.67	50	66.67
Netowork Availability	100	100	100	100	100	100
Network Capacity (Mbytes/sec)	0.25	0.25	0.002	0.002	0.16	0.16
Total Spectrum Occupied (MHz)	0.475	0.475	0.275	0.275	0.275	0.275
Completion Rate	44.99	80.05	76.49	82.16	100	100
Total Messages Requested	1190	1190	591	591	591	591
Total Mbytes Requested	6.08256	6.08256	6.0416	6.0416	6.0416	6.0416
Routable Messages Requested	836	1009	503	591	591	591
Routable Mbytes Requested	4.27008	5.15328	5.14304	6.0416	6.0416	6.0416
Total Messages Generated	836	1009	503	591	591	591
Total Mbytes Generated	4.27008	5.15328	5.14304	6.0416	6.0416	6.0416
Total Air Messages Transmitted	836	1009	503	591	591	591
Total Valid Messages Received at Destinations	536	953	452	486	591	591
Total Corrupted Messages Received at Destinations	300	56	51	50	0	0
Total Mbytes Transmitted Including Relays	4.27008	5.15328	5.14304	6.0416	6.0416	6.0416
Total Valid Mbytes Received at Destinations	2.73677	4.86909	4.62146	4.96406	6.0416	6.0416
Total Corrupted MbytesRecieved at Destinations	1.53331	0.284192	0.521577	0.510243	0	0
Total Messages Dropped	354	181	88	55	0	0
Aggregate Transfer Rate	0.000359434	0.000433778	0.000432916	0.0004608	0.000508552	0.000508552
Mean Transfer Latency	7.63E-07	7.99E-07	0.0470104	0.0496384	2.04E-06	2.04E-06
Mean Message Queue Length	0	0	0	0	0	0
Peak Message Queue Length	0.05597	0.0658913	0.0658913	0	0	0

Figure 13: COMPOSER Results.

the battlefield, integrating with the constructive entities from the MATREX environment. Finally, a Smartphone, tablet, or PC can connect to the local cellular network, or a local wireless network, and integrate with the simulation environment by exchanging data with the CBMS Server and the NVL Toolkit video server. The human role player can interact with the environment via VBS2 and interact with the command and control and situation awareness systems using a Smartphone.

6.4.2 COMPOSER-MATREX Interface

As part of this project, the West Point Department of Systems Engineering worked closely with RDECOM's MATREX program and COMPOSER programs to develop an interface that computed communications effects for messages sent between entities in the MATREX environment. This integration provides a command and control modeling capability that is a significant improvement for the Army's MATREX environment (US Army Research, Development and Engineering Command, 2010). Previous communications effects integrations used high resolution and proprietary communications models that introduced a high computing cost and license fee for MATREX experiments. The COMPOSER integration allowed one computer to manage communications effects in a platoon sized scenario. COMPOSER is a government owned system with no licensing costs. It calculates communications message completion and delays taking into account radio characteristics, terrain, and network loading from other systems. In addition, the project team developed a tool to initialize COMPOSER using data from the Military Scenario Description Language that is also used to initialize the MATREX federation. At the end of this project, this capability has been developed and tested in a small scenario as a proof of concept. Additional testing and development would be needed for a large scale experiment.

6.4.3 CBMS Server

As part of this project, the West Point Department of Systems Engineering worked closely with the Virginia Modeling Analysis and Simulation Center (VMASC), Joint Forces Command J9, and the French Military Academy at St. Cyr to enhance the Coalition Battle Management Language and associated services to support

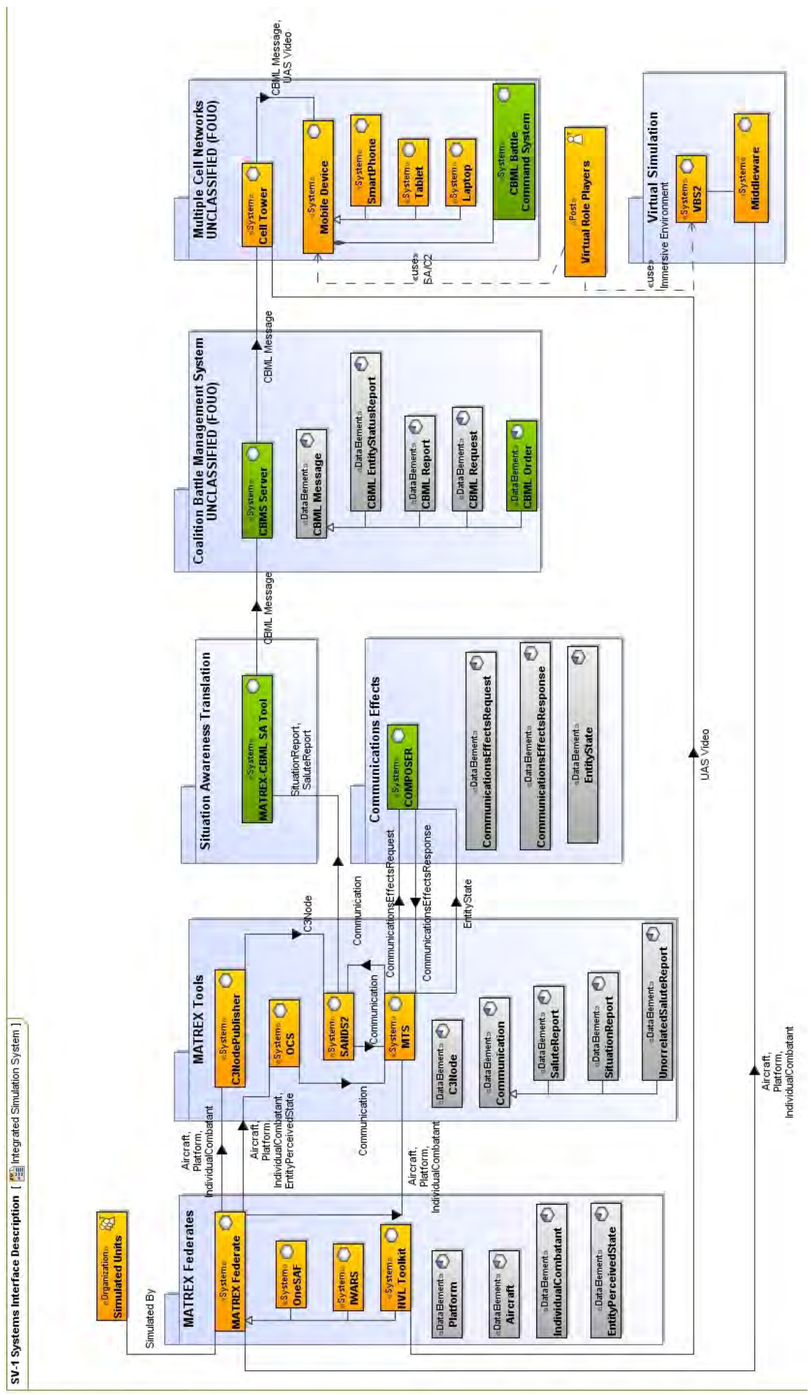

Figure 14: Systems View-1 Resource Interaction Specification for an integrated simulation environment for the experimentation and evaluation of alternative cellular command and control architectures.

dismounted operations. Of particular interest is the ability to pass dismounted orders. The results of this work, described in detail in Section 7, allow virtual role players with Smartphones to pass orders to constructive MATREX entities in OneSAF for automatic execution. This eliminates the need for human "pucksters" to interpret the orders and enter them into OneSAF's user interface. The advantage of this integration is that role players with Smartphones can use the phones to gain situational awareness and immediately issue orders with those phones to take advantage of the increased information.

6.4.4 MATREX-CBML Situation Awareness Tool

In order to pass situation awareness to Smartphone users via CBMS, and interface was created to translate situation awareness messages from the MATREX environment to CBML reports. This interface queries the MATREX Situation Awareness and Display (SANDS2) service for the local operating picture of any friendly entity. SANDS2 responds with a combination of MATREX SaluteReports and SituationReports. These are converted to CBML EntityStatusReports, EntityLocationReports, and EntityHostilityReports. These are passed to the CBML server and made available to command and control systems (Smartphones, tablets, or PC's) that request this information. Since the information is coming from the MATREX environment with communications effects integrated, each role player will only see the information that was passed to him or her based on the capabilities of the cellular network.

6.4.5 CBML Battle Command System

One of the advantages of Smartphones is the ease with which new applications can be developed. In order for the architecture described here to work, an Android app needed to be developed that would allow role players to read situation awareness and issue tactical orders from their Smartphones. The West Point Department of Systems Engineering developed a prototype capability that could perform these tasks in a limited fashion. Only a small subset of the tactical orders addressed in Section 7 were programmed into the phone.

Figure 15: Situation awareness display on Android Smartphone.

The first capability programmed was a situation awareness display, seen in Figure 15. This display uses a Google Maps image as a background to display icons that represent friendly and enemy forces. The gray circular posts represent dismounts, while square posts represent vehicles. The white dots on on the left side of the screen represent activity that has been reported but not yet confirmed as enemy. In addition, the user can zoom in and select any icon to get additional information about that entity as it has been reported. This information is displayed in the text box at the bottom of the screen. After viewing this situation awareness information, the user can select the Frago button to issue a fragmentary order to a subordinate unit for execution.

After selecting the Frago button, the user is presented with a menu of orders that can be given to subordinate units, as shown in Figure 16. For example, the user could select "Advance along a new route" and be presented with the interface in Figure 17. This interface allows him or her to designate the route and waypoints. A subsequent menu can assign a movement technique

Figure 16: List of possible fragmentary orders that can be given to a unit via the Android Smartphone interface.

Figure 17: Android interface to order a unit to move along a new route.

and formation.

7 Coalition Battle Management Language Extensions for Simulation Interoperability

This section addresses the challenge of simulation and command and control interoperability for coalition forces. The Coalition Battle Management Language (CBML) is extended and harmonized with a simulation command and control data model, Primitives of Meaning (POM), using a Model Based Data Engineering Approach (MBDE). This yields a series of extensions to CBML. The first group of extensions allows execution of low-level tactical tasks such as mount a vehicle or orient in a particular direction. Additional extensions allow the specification of detailed execution instructions such as the speed and formation for movement or the posture (kneeling, prone, standing, etc.) for dismounted forces. The last extension allowed CBML orders to be executed by a person or a unit, as opposed to only by a unit. Using these extensions, a data translator developed in this work is able to receive a CBML order and issue it as a POM order. Using the US Army's Modeling Architecture for Testing, Research, and Experimentation (MATREX), the POM order was autonomously issued as a high level architecture (HLA) interaction for execution in the Army's One Semi-Automated Forces (OneSAF) combat simulation. In this manner, the simulation executed the CBML order issued by the command and control system directly, without any additional human interaction.

Coalition partners do not execute tactical missions the same way. Every army accomplishes a mission according to its national doctrine and its own field manuals. A good example of this is the comparison between an ambush organized by a French platoon of the Armée de Terre and an ambush organized by an American platoon of the U.S Army. According to U.S. doctrine and the French doctrine de Saint-Cyr Coetquidan

Direction de la Formation Militaires (2010); Headquarters Department of the Army (2007), the preparation and the first phase of the execution of an ambush are quite the same in both cases: the platoon is divided into three elements, with precise tasks assigned to each element. One of these elements is in charge of detecting the enemy's approach and providing security: it is the security element in the U.S. doctrine or the guet-alerte/couverture/recueil in the French doctrine. Moreover, the two remaining elements have to destroy the enemy forces. In order to do it, the first of these two elements has to provide a primary killing power to fix the enemy into the kill zone: it is the support element or the arrêt in French. Finally, once the enemy forces are isolated and fixed in the kill zone, the last element is therefore able to deliver a large volume of highly concentrated fire into the kill zone in order to kill and destroy as many enemy soldiers and vehicles as possible. This last element is called assault element or destruction.

However, the second phase of the execution of an ambush is very different between French Doctrine and U.S. Doctrine. Indeed, once the two elements in charge of destroying the enemy forces have brought the kill zone under concentrated fire, the French troops have to withdraw immediately, in order to prevent any enemy reinforcement from having the time to reach the ambush site. On the contrary, after this first phase of delivering a large volume of fire, the U.S. platoon leader may assault the kill zone with the assault element, in order to clear and search the area entirely and to gather intelligence.

Consider a company deployed in a multinational theatre and composed of both French and American platoons. Imagine that the company commander is French and wants his American platoon to organize an ambush, and imagine his surprise and his worries in terms of timeline and security when he sees the American platoon assaulting the kill zone of the ambush site whereas he was expecting them to withdraw.

7.1 Primitives of Meaning

In the previous example, it would be very difficult for US and French forces to interoperate with a common understanding of the doctrinal task "ambush." Doing so would require a common understanding of the steps of an ambush, and one country or the other would have to do significant restructuring of doctrinal manuals and retraining to support the agreed upon standard. However, if we decompose the mission term "ambush" into the very basic tasks that the platoon has to execute at the lowest levels, squads and even soldiers, we can express both French and US ambushes using these simple primitives. This is the principle of the POM: decomposing every military operation involving small infantry units into elemental concepts to prevent ambiguity between units. In this way, "interoperability between systems is enabled by the transmission of communications from a transmitting system to a receiving system, and the interpretation of those communications by the receiving system Kewley et al. (2010)." In its current state, POM decomposes dismounted military operations into the following:

Move Moves an individual along a route. The end point of the route is the destination. Includes a movement speed and an optional elevation above ground level for aircraft.

Patrol Similar to move, but upon completion of the route, the entity returns to the start point and circles continuously.

SetWeaponsControlStatus Sets an entity's weapons control status to Free, Tight, or Hold, optionally for a specific area of the battlefield.

Orient Orients an entity in a specific compass direction.

Fire Orders an entity to fire a certain percentage of its magazine an engagement area. This is useful for suppressive fires.

SetPosture Orders a dismounted entity to assume one of several postures, such as standing, kneeling, or prone.

SetWeaponState Orders an entity to stow its weapon, or deploy it for firing.

Observe Orders an entity to observe a specific area of the battlefield.

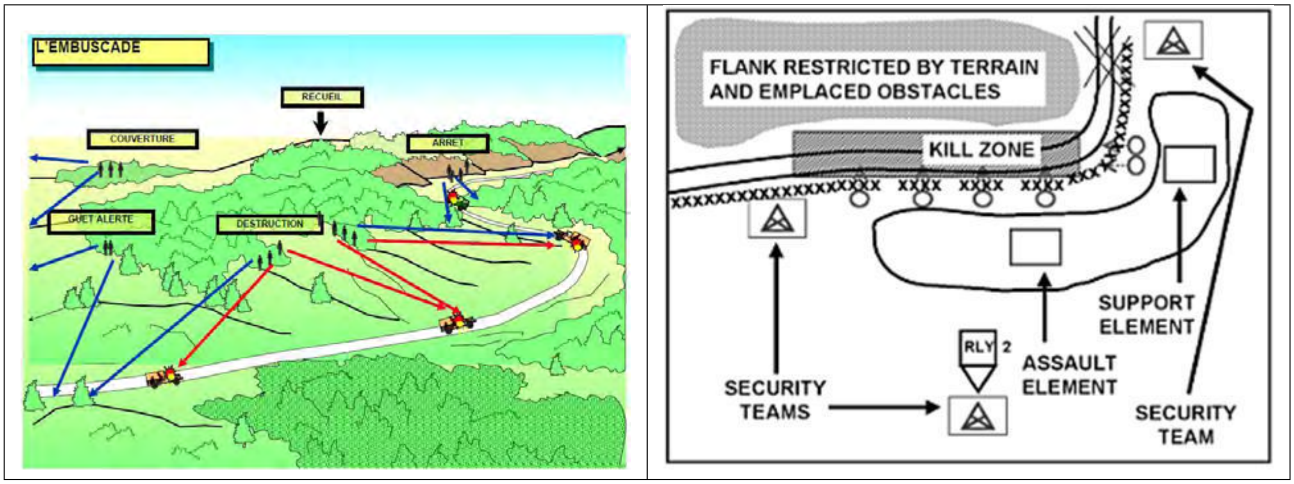

Figure 18: French and US doctrine for an ambush.

SearchEntity Orders an entity to search another named entity. This is useful for searching detainees or traffic control point operations.

Mount/Dismount Orders a dismounted entity to mount or dismount a vehicle.

SearchArea Orders an entity to search a specific area of the battlefield. This is useful for searching for weapons caches.

SearchRoute Orders an entity to search along a specific route looking for hidden improvised explosive devices.

SearchRoom Orders an entity to search a specific room, indicated by a polygon of the room boundaries. This is useful for cordon and search operations.

Halt Orders an entity to stop movement immediately.

SendSignal Orders an entity to send a signal to another entity. A typical use of this field is to signal that an entity is complete with the assigned order. This supports coordinated actions within an operation.

ClearRoom Orders a unit to clear a room.

Using these primitives of meaning, an ambush could be described more accurately in either French or US doctrine.

1. **Move** primitives given to assault, support, and security forces to get them into position and formation.
2. **Orient** primitives given to all forces directing their orientation.
3. Upon identification of enemy in engagement area, **Fire** primitive given to assault force and support force to direct fires in the engagement area.
4. *In US doctrine only*, **SearchArea** primitive given to assault force to search engagement area for useful intelligence.
5. **Move** primitives given to all fores to direct their withdrawl from the ambush area.

This structure accurately captures either the French or US doctrine for an ambush. A command and control system implementing these primitives could give an unambiguous ambush order, as an ordered sequence of primitives, to a platoon using either of the two doctrines.

7.2 Simulation Services as Primitives of Meaning

In order to be able to see the execution of the tasks represented by the Primitives of Meaning in combat simulations the MATREX federation object model (FOM)Hurt et al. (2006); MATREX (2009), used by the US Army's Research, Development, and Engineering Command to federate combat models across engineering domains, has been extended by adding new complex data types and interactions which correspond to the primitives. In order to allow sequences of actions to be simulated, a data type specifying the order of execution and timing for each action has also been added.

7.3 Coalition Battle Management Language

The Coalition Battle Management Language (CBML) is a language using XML-structured documents and based upon Joint Consultation, Command and Control Information Exchange Data Model's (JC3IEDM) MIP-NATO Management Board (2009)entities, attributes and values. CBML has been developed to reach two purposes: command and control of land, naval or aerial forces participating in military operations and improving commanders' awareness of the situation on the battlefield [Need CBML Reference]. That is why CBML is structured in Orders, Reports and Requests.

CBML is much closer to the POM's structure than the JC3IEDM. Each mission in CBML is described by a sequence of tasks that it is possible to order in accordance to the execution of the mission. In addition, each task in CBML is organized into several elements of information which enable the CBML structure to describe precisely the way the task has to be executed.

However, CBML is composed of mission terms and information elements better suited for the operational level of war - moving large forces on the battlefield. It cannot describe basic tasks such as postures, formations and ammo consumption. That is why CBML cannot be directly translated into POM and needs to be extended. Those extensions will be made following the Model-Based Data Engineering methodology.

7.4 Model-Based Data Engineering Methodology

Model-Based Data Engineering is a methodology which aims at enabling the exchange of data elements between heterogeneous systems, by mapping equivalent information expressions from each system to a common reference model Tolk and Diallo (2005). It is composed of four processes: data administration, data management, data alignment and data transformation.

In our case, we chose the POM as the reference model for two reasons. First, POM contains data structures with the highest granularity. Second, the primitives can describe a missions at the tactical level due to the inclusion of tactical tasks in the primitives.. CBML is better suited for higher level operations, lacking the details needed for tactical missions at the company level and below. That is why using the POM as the reference model and extending CBML would enable CBML to be also used as a tactical level command and control tool, in addition to its current capabilities.

7.4.1 Data Administration

The steps of data administration were relatively easy. CBML and POM specifications were each defined in XML schemas with validated examples available for each case. This common feature allowed the following steps to all be performed with available XML tools.

7.4.2 Data Management

After having achieved the data administration phase, the second process that we find in the Data Engineering methodology is data management. This phase is the most important one in the Data Engineering chain. This process "identifies and describes data elements, and maps equivalent information expressions to each other Tolk and Diallo (2005)." In the case of XML-based structures, the main purpose of data management is, therefore, to solve formative and semantic tag-set conflicts between the participating systems. These conflicts are divided into four different classes: semantic, descriptive, heterogeneous, and structural conflicts:

Semantic conflicts occur when local schemata concepts must be aggregated or disaggregated, but fail to exactly match (they might overlap or be subsets of each other, for example).

Descriptive conflicts occur when the same concept is described using homonyms, synonyms, or different names, attributes, slot values, and so on.

Heterogeneous conflicts occur when concepts are described using substantially different methodologies.

Structural conflicts occur when the same concept is described using different structures Tolk and Diallo (2005).

We dealt each of these conflict types in the data management process.

While CBML is able to provide both orders and information about the commander's situation awareness, it cannot describe the basic tasks that soldiers have to execute at the lowest military levels (e.g. changing formation, posture or deciding precise ammo consumption). Therefore, these differences also imply heterogeneous conflicts. CBML is adapted to operational level missions (regiments, brigades and higher), whereas the methodology of the primitives is adapted to tactical level missions (companies, platoons and lower). In order to solve this conflict, we had to make a choice between two solutions. First, we could unpack the CBML high level mission terms by describing the execution of each CBML task with a sequence of POM. However, this solution would require us to make assumptions about what primitives each CBML action-task-activity-code implies. In addition, to keep those assumptions reliable to ensure the exchanged data's credibility and fidelity, we would have to match a precise doctrine and, therefore, add a new entity "DOCTRINE" to CBML and JC3IEDM. Articulating a common doctrine in CBML for the detailed execution of high-level tasks would be difficult.

That is why we chose to focus on another solution. Considering the POM as the reference in our MBDE methodology, adding extensions to the CBML data model, in order to support the basic tasks that soldiers have to execute on the battlefield, would allow us to be find equivalent information expressions to the primitives. This solution had three advantages. First of all, adding those extensions would provide CBML with the capability of being used as a low level command and control tool for tactical operations. Moreover, this solution should be easier to implement, because we would not have to integrate a common doctrine into CBML and JC3IEDM, with all the associations management such a process implies. But above all, we would not need to make assumptions to translate CBML into the primitives with this solution, making the data mapping process much more accurate and efficient. This intellectual process achieved "conceptual mapping" by agreeing "on the data models' conceptual correspondence Tolk and Diallo (2005)" and working to preserve the original design intent of each model.

The attribute mapping step of data management calls for an agreement on which attributes reflect identical concepts on each side. For every single attribute of our POM reference model, we tried to find an equivalent element of information among the CBML attributes and values. The result is shown in Figure 19.

Among the twenty-five different attributes for the POM, only seven need extensions in CBML. This reflects our goal to have a solution implying as few extensions as possible, in order to have the highest natural interoperability between the primitives and CBML. However, this table also points out some descriptive and semantic conflicts. For example, the primitive Fire corresponds to the action-task-activity-code ENGAGE in CBML. Semantic conflicts happen when data information concepts need to be "aggregated or disaggregated, but fail to exactly match." This is the case with the CBML attributes action-task-start-qualifier-code and action-start-temporal-association-category-code as they translate to ActionTrigger in order to represent AfterDelay. This will have to be handled in a the data transformation process.

7.4.3 Data Alignment

We added four types of extension during data alignment to handle the conflicts identified during data ad-

Primitives of Meaning (reference data model)	CBML
Move	what-action-task-activity-code value MOVE or ADVANC
1 - ActionTrigger	when-action-task-start-qualifier-code or when-action-start-temporal-association-category-code
2 - RouteGraphic	where-derived-location-id
3 - MoveSpeed	extension needed as attribute
4 - AltMetersAGL	0.0 (small infantry units only)
5 - Formation	extension needed as attribute
Patrol	what-action-task-activity-code value PATROL
ActionTrigger	when-action-task-start-qualifier-code or when-action-start-temporal-association-category-code
RouteGraphic	where-derived-location-id
MoveSpeed	extension needed as attribute
AltMetersAGL	0.0 (small infantry units only)
Formation	extension needed as attribute
SetWeaponsControlStatus	
ActionTrigger	when-action-task-start-qualifier-code or when-action-start-temporal-association-category-code
6 - WeaponsControlStatus	current-state-report-organisation-status-fire-mode-code
Orient	extension needed as what-action-task-activity-code value
ActionTrigger	when-action-task-start-qualifier-code or when-action-start-temporal-association-category-code
7 - OrientationInDegrees	resource-employment-azimuth-fire-angle
Fire	what-action-task-activity-code value ENGAGE
ActionTrigger	when-action-task-start-qualifier-code or when-action-start-temporal-association-category-code
8 - EngagementArea	affected-who-objet-item-id
9 - PercentOfMagazine	extension needed as attribute
SetPosture	
ActionTrigger	when-action-task-start-qualifier-code or when-action-start-temporal-association-category-code
10 - Posture	extension needed as attribute
SetICWeaponState or SetWeaponState	
ActionTrigger	when-action-task-start-qualifier-code or when-action-start-temporal-association-category-code
11 & 12 - ICWeaponState or WeaponState	extension needed as attribute for both
Observe	what-action-task-activity-code value OBSRV
ActionTrigger	when-action-task-start-qualifier-code or when-action-start-temporal-association-category-code
13- AreaOfInterestGraphic	affected-who-objet-item-id
SearchEntity	what-action-task-activity-code value SERCH
ActionTrigger	when-action-task-start-qualifier-code or when-action-start-temporal-association-category-code
14 - EntityToSearch	where-derived-location-id
Mount	extension needed as what-action-task-activity-code value
ActionTrigger	when-action-task-start-qualifier-code or when-action-start-temporal-association-category-code
15 - VehicleToMount	affected-who-objet-item-id
Dismount	extension needed as what-action-task-activity-code value
ActionTrigger	when-action-task-start-qualifier-code or when-action-start-temporal-association-category-code
SearchArea	what-action-task-activity-code value SERCH
ActionTrigger	when-action-task-start-qualifier-code or when-action-start-temporal-association-category-code
16 - SearchAreaGraphic	where-derived-location-id
17 - DurationOfSearchInSeconds	when-action-task-maximum-duration
SearchRoute	what-action-task-activity-code value SERCH
ActionTrigger	when-action-task-start-qualifier-code or when-action-start-temporal-association-category-code
RouteGraphic	where-derived-location-id
SearchRoom	what-action-task-activity-code value SERCH
ActionTrigger	when-action-task-start-qualifier-code or when-action-start-temporal-association-category-code
18 - RoomGraphic	where-derived-location-id
Halt	extension needed as what-action-task-activity-code value
ActionTrigger	when-action-task-start-qualifier-code or when-action-start-temporal-association-category-code
SendSignal	extension needed as what-action-task-activity-code value
ActionTrigger	when-action-task-start-qualifier-code or when-action-start-temporal-association-category-code
19 - SendTo	affected-who-objet-item-id
20 - Signal	extension needed as attribute
21 - MessageReveiverType	affected-who-objet-item-type
22 - MessageTransmissionType	extension needed as attribute
ClearRoom	what-action-task-activity-code value CLRLND or CAPTUR
ActionTrigger	when-action-task-start-qualifier-code or when-action-start-temporal-association-category-code
23 - StackLocation	current-state-report-object-item-location
24 - StackLocation	current-state-report-object-item-location
RoomGraphic	where-derived-location-id
25 - EntranceLocationGraphic	where-derived-location-id
UnitCommand	taskee-who-organisation-ref UnitRef type
SingleEntityCommand	extention needed as taskee-who-organisation-ref type

Figure 19: Attribute mapping for CBML and POM.

ministration, shown in Figure 19. Five new action-task-activity-code-value entries were added for the five missing tasks mount, dismount, halt, orient, and send signal. Five optional fields were added to the ACTION-RESOURCE-EMPLOYMENT entity to handle formations, movement speed, signal text, signal type, and ammunition expenditure. Two optional fields were added to ORGANISATION-STATUS to handle weapon state and posture. Finally, taskee-who-organisation-typeref was extended by adding PersonRef to allow CBML to task persons in addition to units. Collectively, these extensions imposed minimal changes to CBML and did not depart from the original intentions of the modified elements as they are described in CBML documentation Simulation Interoperability Standards Organization (2010).

7.4.4 Data Transformation

During data transformation we built a program that would transform a CBML file that is compliant with our extensions to a POM file. During content mapping, the translator needed to define the mathematical relationships between the equivalent attributes defined during data administration. While most of the transformations involved moving data directly from a CBML attribute to the corresponding POM attribute, two particular entities required additional effort.

In CBML, a phase, a task, and a primitive are each identified by the TASK entity. The context and ordering of tasks enables us to map to the following three cases:

- If the Tasker and Taskee of the Task are the same (an organisation is tasking itself), consider the task a phase.
- Consider each successive task to a single Taskee to be a primitive.
- Aggregate successive primitives to a single Taskee into a task to be executed by that Taskee during the phase.

In CBML, there is no direct way to represent starting a task after a delay. The CBML XML tag-set When can have three types of child elements: AbsoluteTime, RelativeTime and AbsoluteRelativeTime. The child AbsoluteTime indicates that the Task has to be executed at a precise moment of the mission, reflected by an absolute date. However, the child RelativeTime is used when the execution of the Task depends on the execution of a reference Task. This is appropriate when you want a Task to be executed after, or before, the end, or the beginning, of another reference Task. But it is also possible to find in structure of CBML the child AbsoluteRelativeTime which contains all the properties of the two previous children of the element When. AbsoluteRelativeTime reflects that the CBML Task has to be executed both according to a precise date and depending on another reference Task. We chose to translate the element AbsoluteRelativeTime into the primitives' TriggerType "AfterDelay" because it allowed us to calculate the delay before the execution of the Task by having two dates at our disposal: one reflecting when the Task that has to be executed and one belonging to the reference Task. By performing the subtraction between the date of the Task and the reference date, we get the value of the primitives' attribute DelayInSeconds corresponding to the TriggerType "AfterDelay".

7.5 Tactical Mission Example

In order to exercise the coalition and simulation interoperability enabled by our research, we have chosen to represent a tactical support by fire mission through a French OPORD, and we want to be able to see the execution of this mission into the simulation tools of the U.S Army. Therefore, our goal is to generate a CBML-compliant XML file from the French OPORD with our interface, and then translate this CBML-compliant document into an XML document using the structure POM, which is understandable by the OneSAF simulations thanks to the extensions made to the MATREX FOM.

The mission of the 1st French Platoon in Table 1 shown in Figure 20 is to provide support by fire on the house named Oscar 2, from the wood corner named Oscar 1. In order to accomplish this mission, the 1st Platoon has to advance to Oscar 1 through an intersection named Hotel 1, where the squads have to change their postures

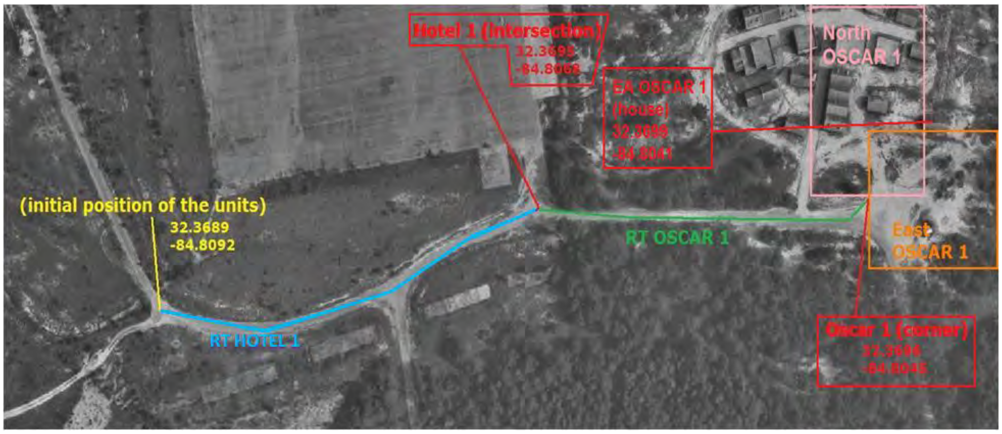

Figure 20: Tactical graphic for French OPORD.

JE VEUX: Appliquer des feux sur l'ENI situé au niveau de EA Oscar 1 à compter du 02 octobre 2010 à 06h30 pour au mieux détruire au pire chasser l'ENI qui l'occupe. POUR CELA :
Me déplacer en ambiance sûreté jusqu'à l'intersection en 32.3695 º N 84.8068 º O, baptême terrain Hotel 1, puis en ambiance discrétion jusqu'à la corne de bois en 32.3696 º N 84.8045 º O, baptême terrain Oscar 1, pour y installer un dispositif de surveillance et d'appui sur EA Oscar 1 pour 06h00.
En liaison permanente avec le 2nd PLT, appliquer des feux sur l'ENI situé au niveau de EA Oscar 1 à compter du 02 octobre 2010 à 06h30.
Me renseigner et renseigner la compagnie et le 2nd PLT sur l'activité ENI dans et autour EA Oscar 1.
EMD: Mettre en place un dispositif de surveillance face au Nord et à l'Est à partir des limites Ouest de EA Oscar 1 et à compter du 02 octobre 2010 06h35.

Table 1: Tactical mission described by French OPORD and tactical graphic.

to reach Oscar 1 in a stealth mode. Moreover, the Platoon has to open fire at 6:30 AM, in order that the 2nd Platoon can capture Oscar 2 for no later than 6:45 AM. Finally, once the 1st Platoon has brought the objective under fire, it has to shift its fires toward North and East, in order to prevent any enemy forces from pulling out of the house or reinforcing OSCAR 2 from vicinity of the objective during the assault of the 2nd Platoon.

Through a CBML command and control user interface we developed for this project, we expressed the OPORD in a CBML compliant structure that could be understood and read into any other C2 system that was compliant with the CBML standard. The translator read the CBML file and created a Primitives of Meaning file that could be sent to the simulation for execution. The primitives data is displayed in the Primitives of Meaning user interface shown in Figure 21. The Primitives of Meaning GUI translates this OPORD into a set of MATREX FOM interactions that can be read by OneSAF and executed as shown in Figure 22.

This example shows the capability of both France and the United States to take part in simulated multinational exercises with the POM as a simulation data model, the CBML as a command and control data model which matches the NATO standard JC3IEDM, and with our translator program as a link between those two data models.

7.6 Other Potential CBML Extensions

This section has demonstrated a technical approach and sample case that allows a CBML compliant command and control system to issue an operations order for direct execution by a simulation, without any additional human intervention. This capability is enabled

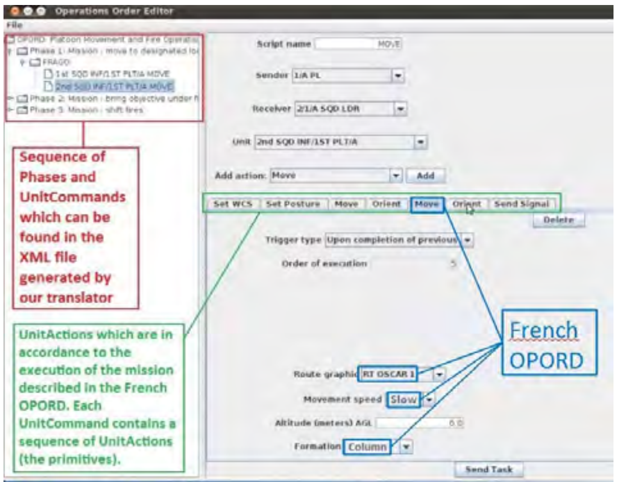

Figure 21: POM file generated by translator using CBML compliant expression of French OPORD.

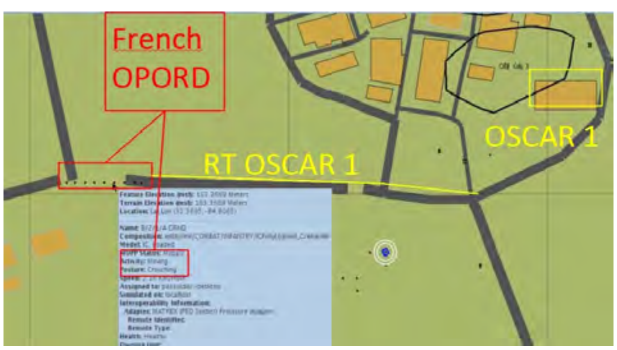

Figure 22: Execution of French OPORD in OneSAF.

by the concept of primitives of meaning, the expression of low-level tactical actions as a series of unambiguous primitives that can be executed by coalition forces or by the simulation. The extensions of CBML derived through MBDE allowed CBML to handle this concept.

While this effort has been applied to the dismounted infantry domain, a similar approach would work for other domains. In the air-to-air combat domain, for example, a team of operational experts would need to define the necessary primitives that can be ordered by air forces engaged in air to air combat. They would need to extend CBML using a similar MBDE approach to handle these new primitives. They would also need to build the simulation infrastructure and capability to receive these primitives and react accordingly. Finally, they would need to extend their command and control systems to issue orders using these extensions. Once complete, coalition partners could execute a joint training exercise where air planners from each partner issued air orders that could be understood by their partners and automatically executed by the simulation.

8 Analysis and Recommendations

In order to compare our alternatives, a combination of system properties, simulation results, and constructed scale value judgments were collected in a raw scoring data matrix for each alternative. Each element of raw data is scored using the value functions in ANNEX B in order to generate value scores between 0 and 100 in the value matrix. Each value score is multiplied by its normalized swing weight, shown in Figure 6, to generate the additive value for that particular evaluation measure.

When these are totaled, we get the total value model shown in Figure 23. In this graphic, the total value for each alternative is compared to an ideal solution, which has the best possible score for all value measures, and an "All Star" solution, which combines the best scores for our alternatives into one solution. These comparisons not only show which of the alternatives scores best, but also how each alternative could potentially be improved to return more value. From these charts, we can see that each solution has its strengths and weaknesses. The SINCGARS gets high scores for its voice capabilities, but it lacks a screen for video or situation awareness displays. It is also fairly heavy. The Nett Warrior offers significant improvement, but it is still fairly heavy with limited video resolution. The Smartphone and tablet solutions offer the greatest total value, mostly due to their ease of use and low weight. But this comes with slightly lower transmission ranges and some security risks.

Additional value may be gained by engineering increased security and increased radio range into the alternatives. Some of this is represented in the architecture shown in Figure 7. A candidate solution provided by Lockheed Martin, was tested in the CSDA program with mixed results (Army Evaluation Task Force AETF, 2010). The test, however, did demonstrate the feasibility of a cellular solution and some ability to engineer increased capabilities into the system.

Cost comparison between alternatives was difficult because each system was in a different stage of the life cycle. In the case of programs of record, unit costs depended upon order quantity. In the case of experimental systems, vendor cost claims can be misleading, because all requirements are not engineered into the prototypes. However, a rough order of magnitude comparison is illustrative. The SINCGARS (ASIP) radio is by far the cheapest system, because it is already fielded. The CSDA program provided a rough order of magnitude cost of $2.1 million to outfit a battalion with a secure cellular network. A cost estimate on the Nett Warrior System is about $24,000 per system. If the Nett Warrior is used down to squad leader level, a battalion will require 81 systems (aim, 2010), yielding a total cost of nearly $2 million. If the basis of issue is down to the team leader level, the Nett Warrior cost nearly doubles to $3.7 million. At this point, the commercial cellular solution is less expensive. In essence, the network infrastructure is the primary cost driver for the cellular system. Once the infrastructure is in place, the price per additional user is simply the price of a commercial cell phone and any enhancements to that phone necessary for military operations. Additionally, since software development on commercial systems is typically cheaper, the overall software development and maintenance prices would be cheaper. A similar savings would be had for training, due to the ease of use and simplicity of commercial systems.

Our team recommends that the Army test and evaluate a commercial cellular architecture, similar to the one shown in Figure 7, as an alternative to the Nett Warrior system. Our analysis shows that this system delivers more value to the stakeholders at potentially half the price. Because it leverages commercial technology, it will have the added advantage of easier maintainability, upgrade-ability, and interoperability with partners who also use commercial technologies. Prior to adoption, the program manager must integrate security considerations and increased radio range into the overall solution. Some potential solutions are addressed in Section 5. In addition, as the program team builds battle command applications, we recommend they consider adopting NATO standards such as the Coalition Battle Management Language so that allied partners can integrate with US forces who use this architecture.

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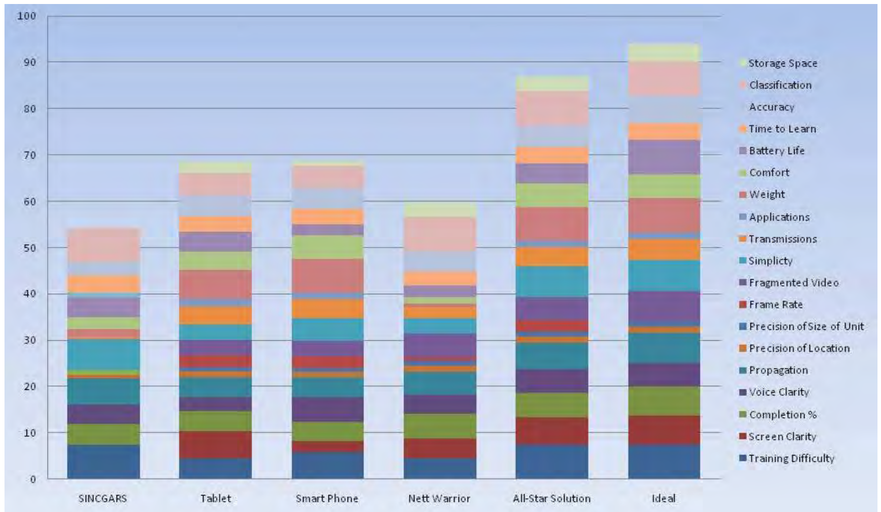

Figure 23: Total value for each alternative.

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ANNEX A - OV-5b - Operational Activity Models

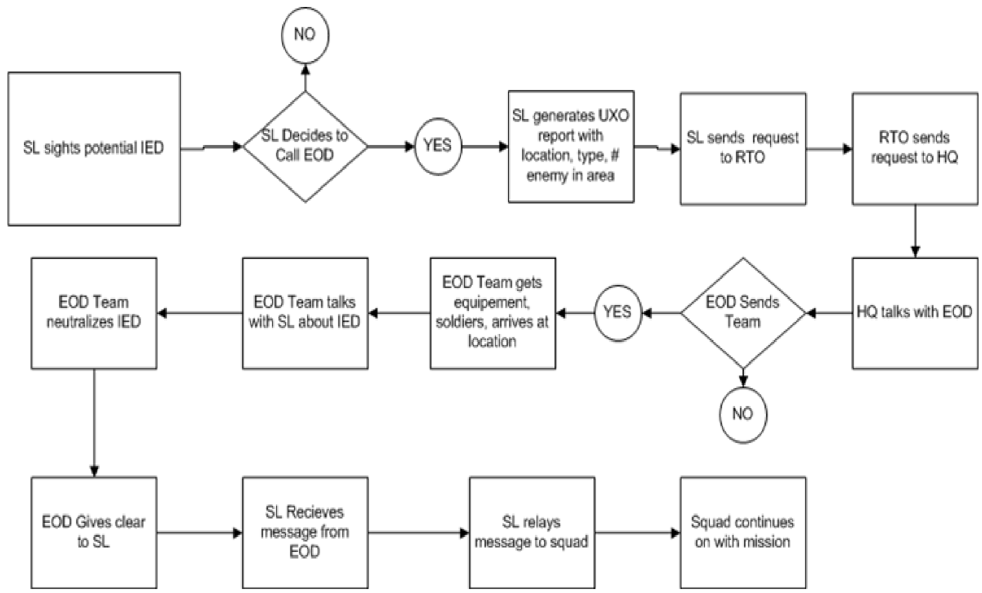


Figure 24: Find IED Mission Thread

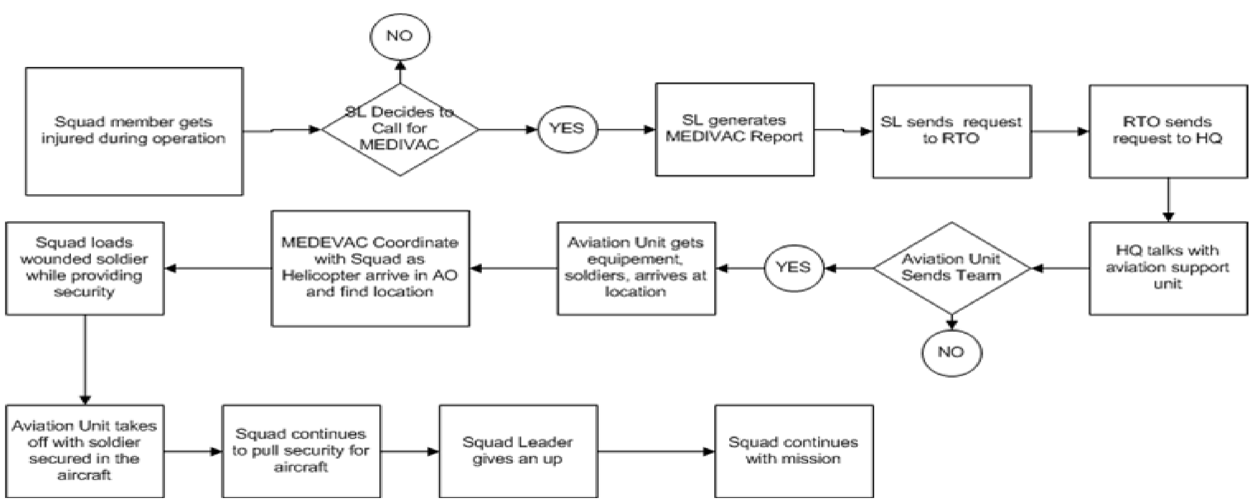


Figure 25: MEDEVAC Mission Thread

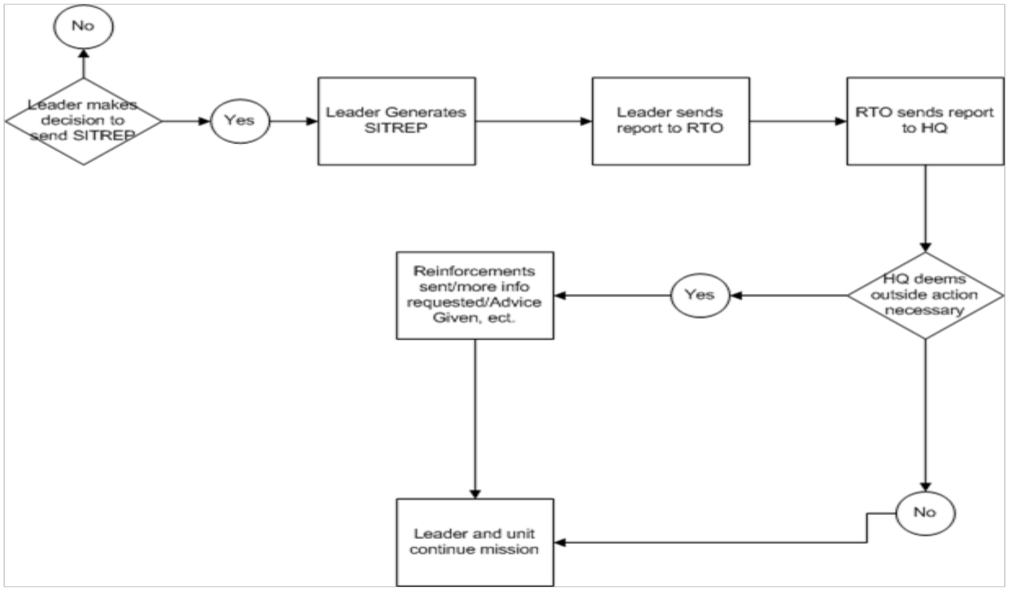


Figure 26: SITREP Mission Thread

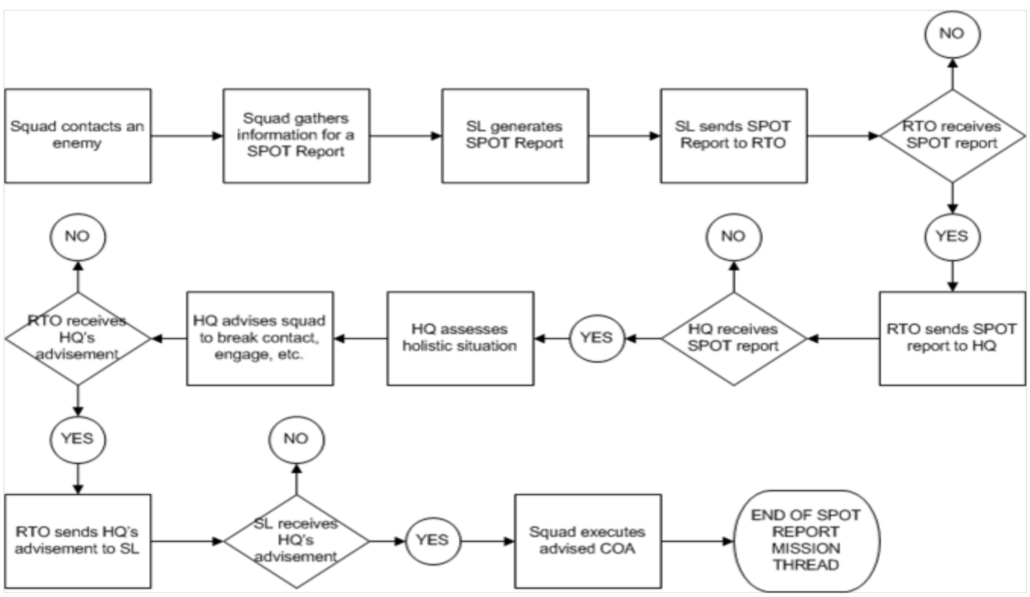


Figure 27: Spot Report Mission Thread

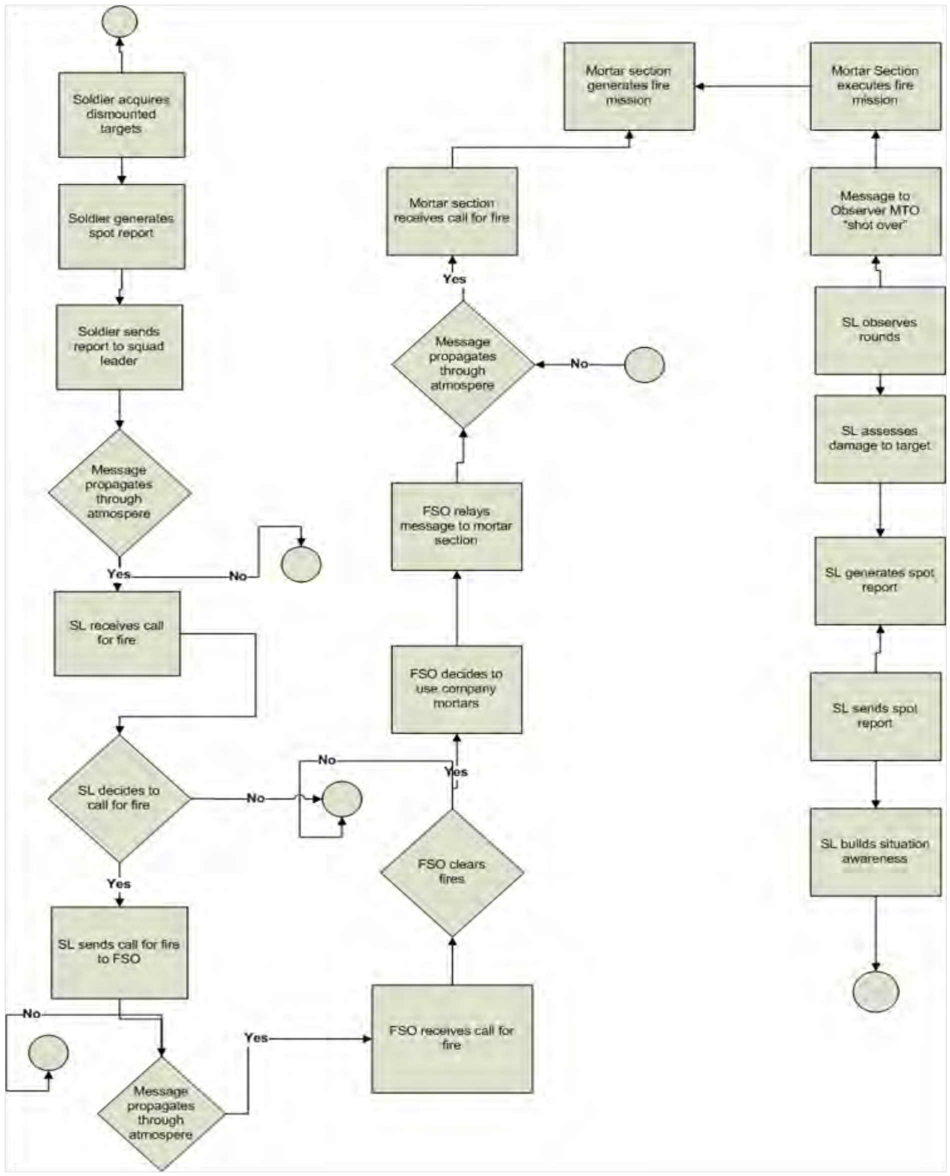


Figure 28: Call for Fire Mission Thread

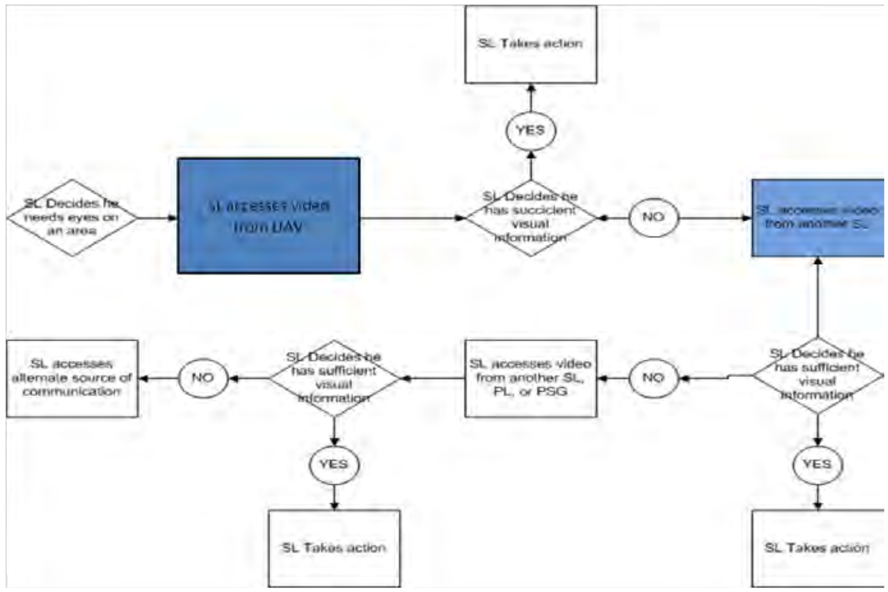


Figure 29: Video Feed Mission Thread

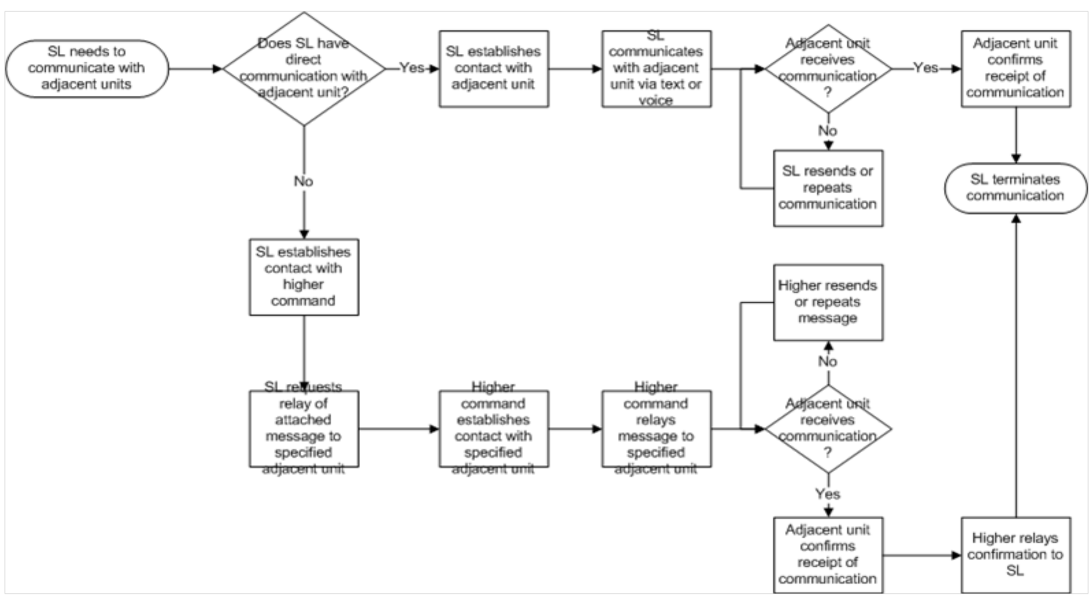


Figure 30: Communicate with Adjacent Units Mission Thread

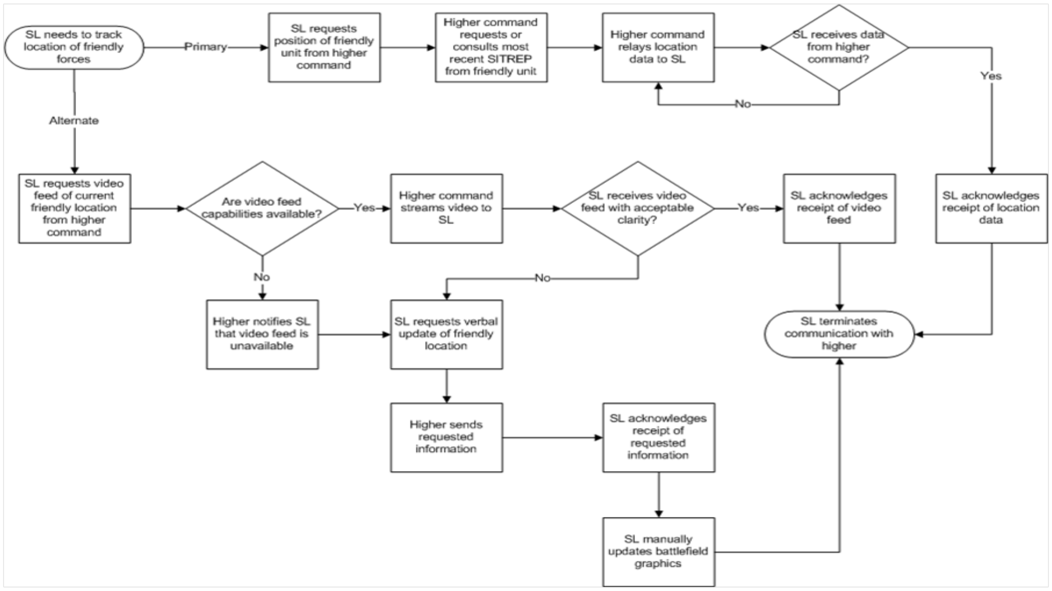


Figure 31: Track Allied Forces Mission Thread

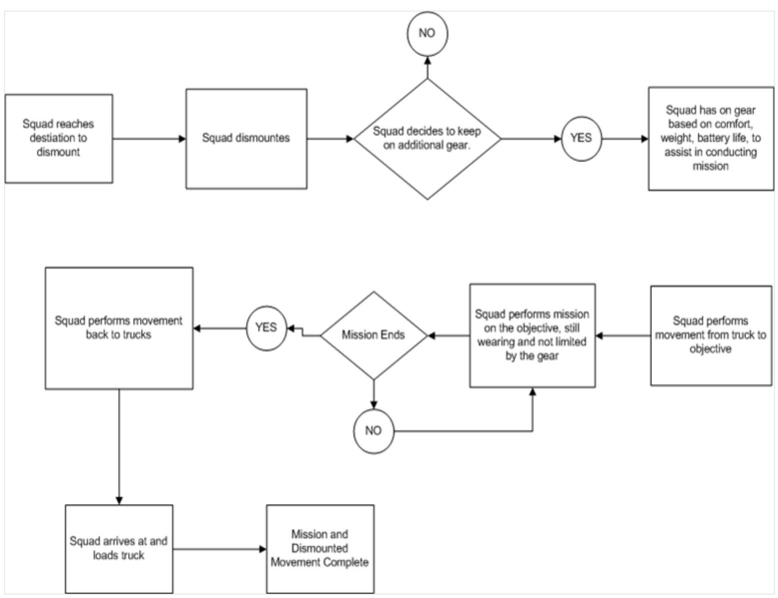


Figure 32: Dismounted Movement Mission Thread

ANNEX B - System Functions, Objectives, and Value Measures

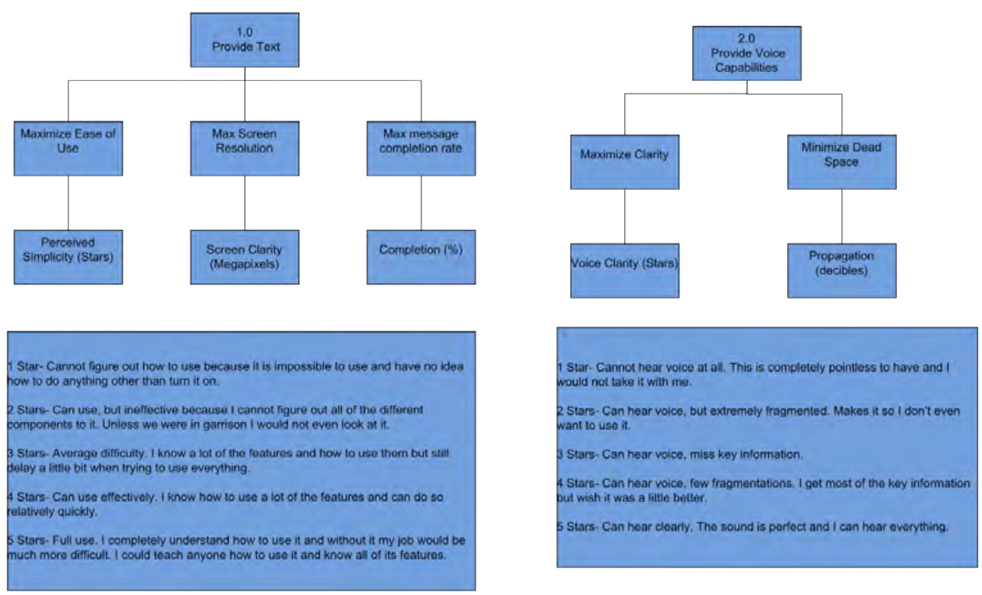


Figure 33: System functions, objectives, and value measures for text and voice functions.

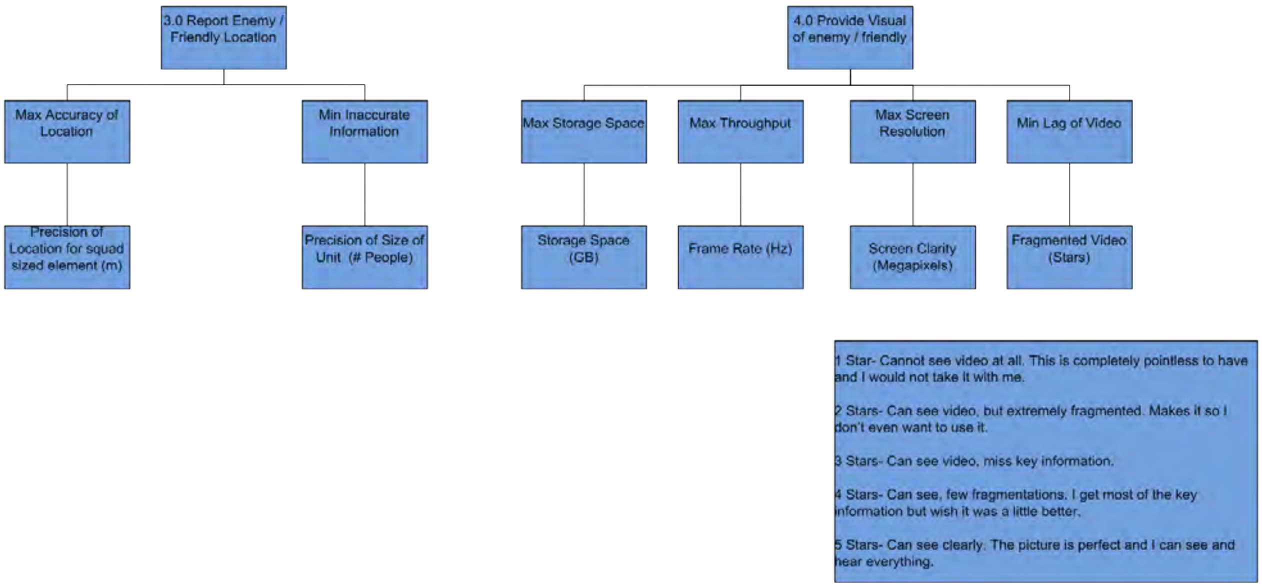


Figure 34: System functions, objectives, and value measures for report friendly/enemy and provide visual functions.

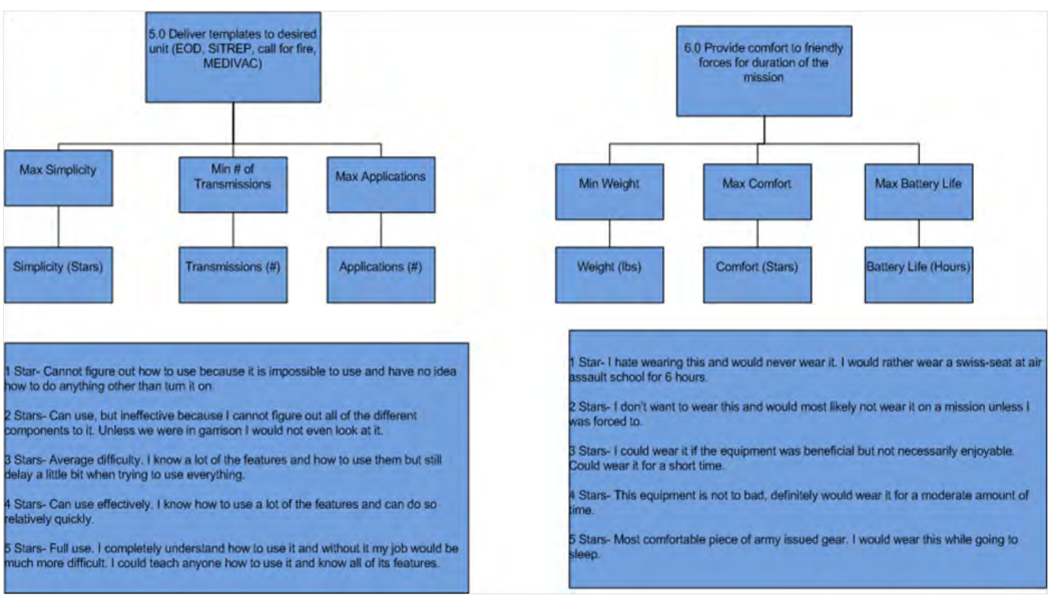


Figure 35: System functions, objectives, and value measures for reporting template and comfort during dismounted movement functions.

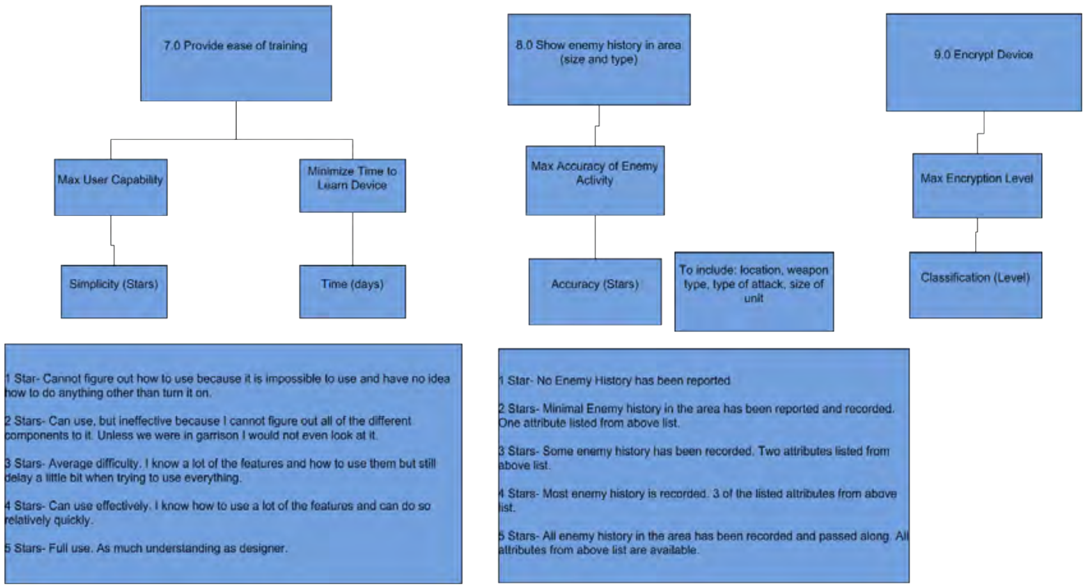
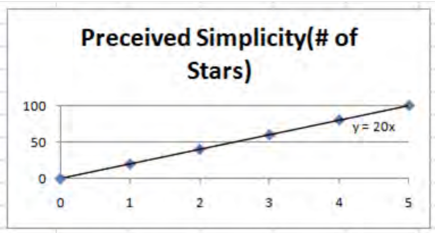


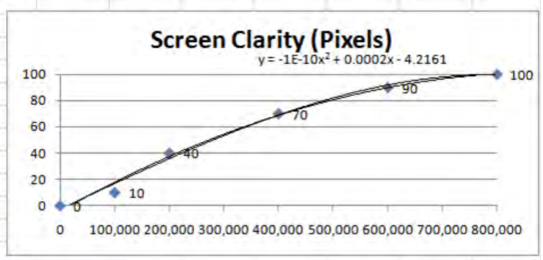
Figure 36: System functions, objectives, and value measures for training ease, enemy activity, and encryption functions.

ANNEX C - Value Models

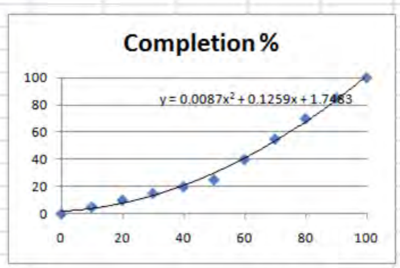
Preceived Simplicity(# of Stars)	Value
5	100
4	80
3	60
2	40
1	20
0	0
Score	Value Function
3	60



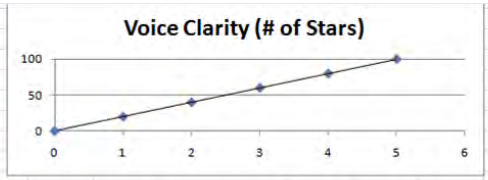
Screen Clarity (Megapixels)	Value
800,000	100
600,000	90
400,000	70
200,000	40
100,000	10
0	0
200,000	40.2161



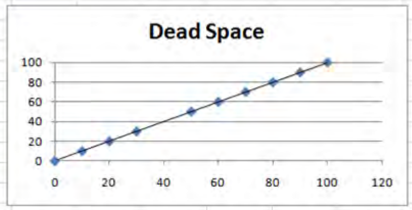
Completion %	Value
100	100
90	85
80	70
70	55
60	40
50	25
40	20
30	15
20	10
10	5
0	0



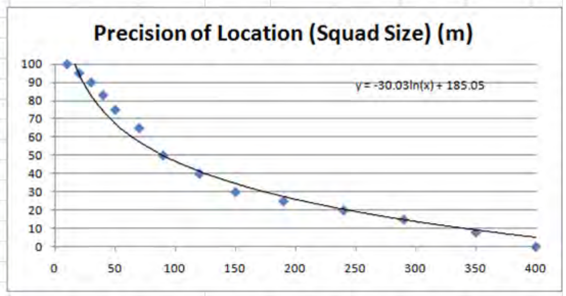
Voice Clarity (# of Stars)	Value
5	100
4	80
3	60
2	40
1	20
0	0



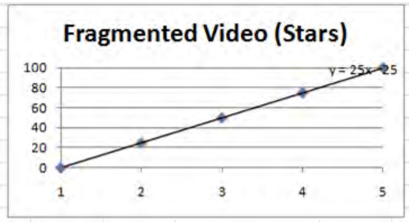
Dead Space (Decibels)	Value
100	100
90	90
80	80
70	70
60	60
50	50
30	30
20	20
10	10
0	0



Precision of Location (Squad Size) (m)	Value
10	100
20	95
30	90
40	83
50	75
70	65
90	50
120	40
150	30
190	25
240	20
290	15
350	8
400	0

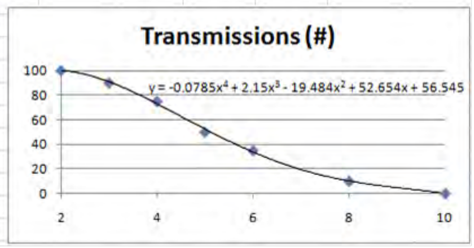


Fragmented Video (Stars)	Value
5	100
4	75
3	50
2	25
1	0

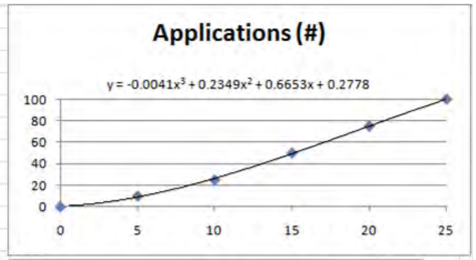


Simplicity (Stars)	Value
5	100
4	75
3	50
2	25
1	0

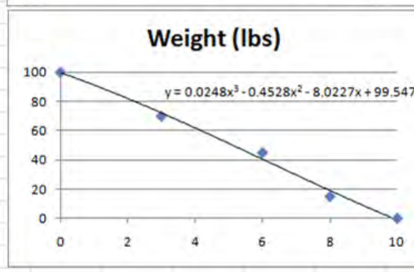
Transmissions (#)	Value
2	100
3	90
4	75
5	50
6	35
8	10
10	0



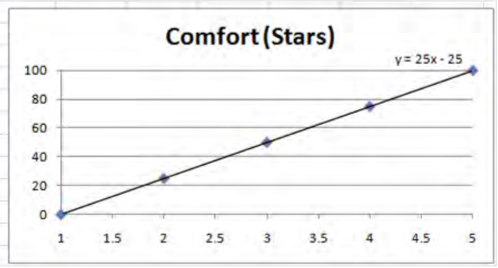
Applications (#)	Value
25	100
20	75
15	50
10	25
5	10
0	0



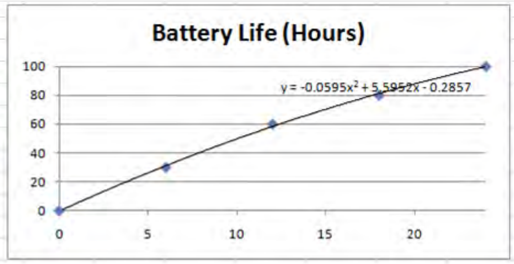
Weight (lbs)	Value
0	100
3	70
6	45
8	15
10	0



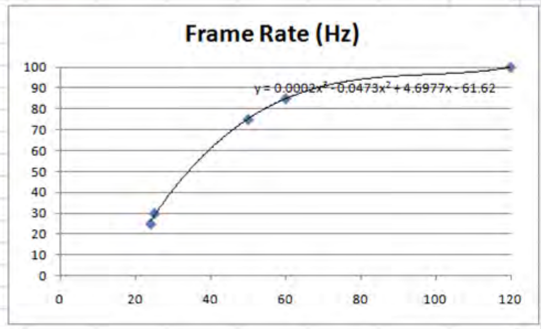
Comfort (Stars)	Value
5	100
4	75
3	50
2	25
1	0



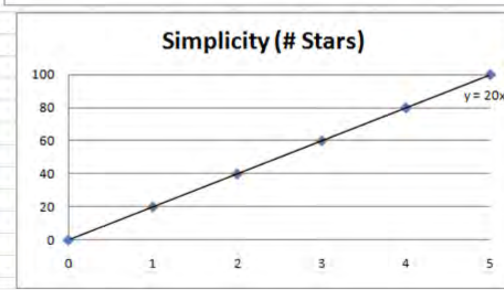
Battery Life (Hours)	Value
24	100
18	80
12	60
6	30
0	0



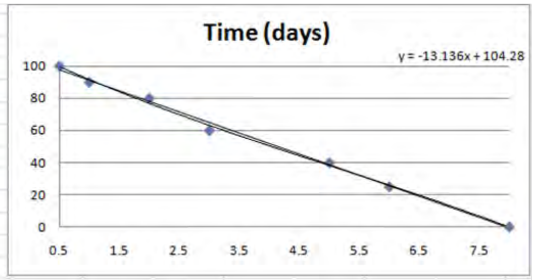
Frame Rate (Hz)	Value
24	25
25	30
50	75
60	85
120	100



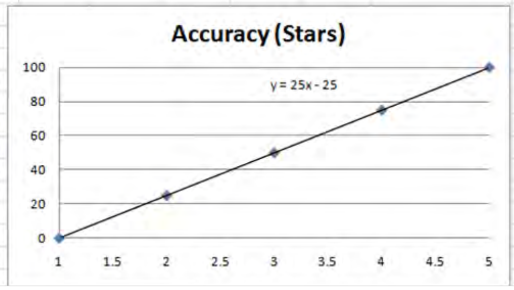
Simplicity(# of Stars)	Value
5	100
4	80
3	60
2	40
1	20
0	0



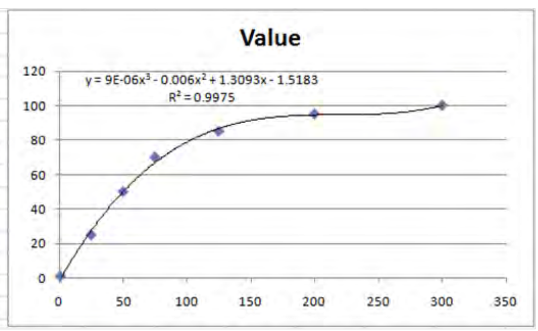
Time (days)	Value
0.5	100
1	90
2	80
3	60
5	40
6	25
8	0

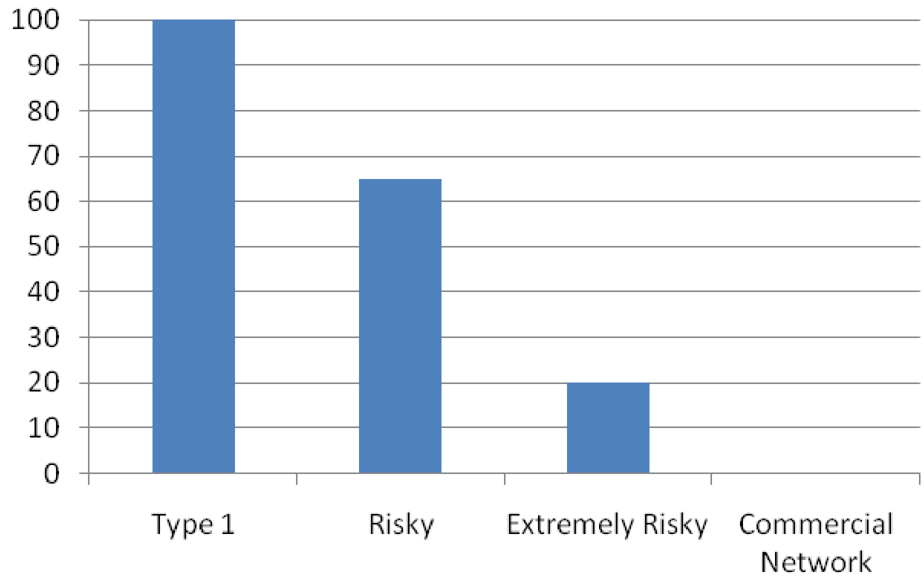


Accuracy (Stars)	Value
1	0
2	25
3	50
4	75
5	100



Storage Space (Gigs)	Value
1	1
25	25
50	50
75	70
125	85
200	95
300	100





Classification	Value
Type 1	100
Risky	65
Extremely Risky	20
Commercial Network	0

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14. ABSTRACT

As compared to their mounted peers, dismounted soldiers lack effective radio communications, situation awareness displays, and request or reporting systems that integrate with other elements of the combined arms team. This project looks to emerging commercial technologies for mobile cellular networks as a cost effective means to fill these gaps. These technologies are in wide use across the international commercial sector and allow robust and high bandwidth communications in a very small package. They are employed in all types of terrain, and international standards have emerged that allow communications between disparate systems. The study team concluded that a brigade/battalion owned CDMA network delivered the most value at the lowest cost as compared to Nett Warrior systems. This is a standalone unclassified network owned by the brigade. The brigade decides who to allow to enter the network and what information to provide on that network. The network consists of static cell towers on bases, mobile cell towers in vehicles, and, if necessary, dismounted cell towers covering small patrols.

15. SUBJECT TERMS

Dismounted Operations, Command and Control, Cellular Technologies, Modeling and Simulation

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